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Progress Report

CONTROL OF BARK BEETLES WITH RESIDUAL-TYPE INSECTICIDES - STUDIES ON STATES OF DEPOSITS

1957

By Robert L. Lyon

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CALIFORNIA FOREST AND RANGE EXPERIMENT STATION
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Agriculture--Forest Service, Berkeley, California

U.S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE
CALIFORNIA FOREST AND RANGE EXPERIMENT STATION
Division of Forest Insect Research

Progress Report

CONTROL OF BARK BEETLES WITH RESIDUAL-TYPE INSECTICIDES

STUDIES ON STATES OF DEPOSITS

1957

By Robert L. Lyon

SUMMARY

Certain of the factors that control the states of deposits of DDT, dieldrin, and endrin were studied. In laboratory studies, 3- by 3-inch sections of fibreboard were used as an experimental substrate on which the deposits were prepared. Toxicity was measured by bioassay with the California five-spined engraver (Ips confusus (Lec.)). Simulated field tests of laboratory results with DDT were also begun on ponderosa pine infested with the western pine beetle (Dendroctonus brevicomis Lec.) and the California five-spined engraver. The principal findings were as follows:

Laboratory tests:

1. The decreasing order of potency of DDT-, dieldrin-, and endrin-acetone deposits was: endrin > dieldrin > DDT.

2. DDT deposits were composed of acicular crystals, frequently arising in clusters from a common point, and an amorphous, granular incrustation. Dieldrin deposits were also composed of acicular crystals indistinguishable from those of DDT. An incrustation was also present though much lighter. Endrin deposits were composed entirely of granular particles, many amorphous but others with definite crystal form, usually hexagonal.

3. Increasing levels of dose (amount of insecticide applied per unit area) had variable effects on toxicity. Based on 1-minute exposure periods, dose levels of 320 to 2,560 mg./ft.^{2} in increments of 160 mg. brought the toxicity of endrin deposits to 100 percent well before the maximum dose was reached. With the same dose levels, DDT deposits showed maximum toxicity (c. 50 percent) at the lower dose levels with little change thereafter.

Dieldrin deposits tested at dose levels of 80 to 640 mg./ft.^{2} in increments of 40 mg. showed maximum toxicity (c. 85 percent) at the lower dose levels, as did DDT, and also changed little with increasing dose.

4. Increasing levels of dose had variable effects on states of deposits. Endrin deposits showed progressively greater crystal density and crystal coverage with increasing dose. Crystal structure was unaffected by dose. With DDT deposits, crystal density was not noticeably changed by increasing levels of dose but coverage increased and the proportion of long acicular crystals decreased. The behavior of dieldrin was unique. Crystal size and density were unaffected by dose but coverage increased to an optimum as dose was raised and then decreased again with further increments of dose.

5. Coverage was the biggest variable of deposits of DDT and dieldrin, yet mortality was only slightly affected as coverage was increased from 10 to 100 percent. In tests of both insecticides, mortality rose to its maximum as coverage increased from 0 to 10 percent. The insect may become saturated with crystals on deposits showing about 10 percent coverage so that further improvement in coverage can show no corresponding effect on mortality.

6. Concentration (insecticide/solvent ratio) had no effect on toxicity or states of deposits of DDT in contrast to dieldrin deposits which were strongly affected.

7. DDT deposits were unaffected by the moisture content of the fibreboard substrate at the time the insecticide was applied, notwithstanding the use of the water soluble carrier acetone or water insoluble carrier xylene.

8. Beetles confined to deposits of DDT beneath a watch glass were not affected by the vapor of the insecticide during an exposure period of 20 minutes or less. This method of exposure, therefore, for determining contact toxicity is not invalidated by a fumigating action of DDT.

9. DDT deposits were generally more toxic when exposed to sunlight than they were when completely shielded from sunlight. Deposits of 320 and 640 mg. DDT/ft.^{2} were most improved by intermediate intensities of solar radiation, whereas deposits of 1,280 mg. were most improved by maximum solar radiation. A dose of 320 mg./ft.^{2} exposed to maximum sunlight was the only instance where a deposit was less toxic than comparable deposits completely withheld from exposure to sunlight. The beneficial effects of solar radiation were being

offset to some extent by deteriorating effects, noticeable by comparing toxicities of the 1- and 2½-month-old deposits.

10. DDT deposits were still highly effective after 2½ months of exposure to sunlight. Such long-lasting toxicity is enough to provide a toxic bark-surface deposit throughout the emergence period of a bark beetle brood.

Field Tests:

1. DDT-xylene deposits of 320, 640, and 1,280 mg./ft.^{2} on ponderosa pine killed 49, 71, and 70 percent of the emerging brood of D. brevicomis adults, respectively. The higher mortalities obtained from the two heaviest doses were due to better crystal coverage and density. The highest dose of 1,280 mg. had much of its crystal growth in the form of tightly packed crystal aggregates, less available to the insect, which probably accounted for the failure of this dose to show a higher mortality than the 640 mg. dose.

2. DDT-xylene deposits of 320, 640, and 1,280 mg./ft.^{2} on ponderosa pine killed 82, 88, and 95 percent of the emerging brood of I. confusus adults, respectively. Thus, toxicity increased directly with dose. Correlated with this increasing toxicity was an increasing proportion of long acicular crystals and increasing crystal coverage.

3. The high mortalities of the emerging bark beetles that resulted from DDT applications to infested ponderosa pine show that residual-type insecticides promise to provide effective control. The promise of effective control is strengthened in the light of past studies that have shown most residual-type insecticides to be more toxic than DDT.

4. Ostomid and clerid predators emerging from DDT-treated ponderosa pine were unaffected by the insecticide.

A spray chamber was evaluated for usefulness in studies on states of deposits and was found to produce deposits which can be controlled within a standard deviation of 3 to 6 percent. The chamber has been redesigned to accommodate the special requirements of deposit studies. A nozzle holder was also designed that permits the accurate replacement or substitution of nozzles and prevents variability in the deposits due to slight changes in nozzle position.

A turntable was designed and constructed so that more accurate and uniform application of insecticides can be made to pine bolts in the simulated field tests of laboratory findings.

INTRODUCTION

Many of the organic, residual-type insecticides have proven to be highly toxic to bark beetles (6,9,10). The control of these beetles while emerging from or attacking a host tree, promises to be effective if a highly toxic deposit of these insecticides can be made on the bark surface. The deposit must be toxic enough to kill in spite of the characteristically brief periods of time the bark beetle contacts the bark while entering or leaving the host tree.

An understanding of the behavior of insecticides when applied to an absorbent surface like bark is essential if effective control is to be obtained. The physical structure of deposits (states of deposits) is determined by a great many factors including the substrate, the insecticide, its formulation and method of application, and the environment. Toxicity is, in turn, dependent on the state of the deposit. Studies on these relationships were begun in 1956 (7) and they are the subject of this report.

Field studies were carried out at the Miami Field Base, a laboratory maintained by the Forest Service, United States Department of Agriculture. I am indebted to Richard W. Bushing for his able assistance and particularly for his contributions toward the design and construction of equipment necessary to the program.

MATERIALS AND METHODS

Materials and methods were discussed in detail in the 1957 progress report (7) and will be treated only briefly here.

The California five-spined engraver, Ips confusus (Lec.), was used as the test organism to bioassay deposits prepared on 1/8-inch thick, untempered, 3- by 3-inch sections of compressed fibreboard.

The insecticides tested were DDT, dieldrin, and endrin.[1/] The active principle was c. 100 percent, 85 percent, and 93.4 percent respectively and formulations were based on the active principle.

The insects were reared from ponderosa pine in an outdoor, wire-screen insectary; collected individually in size #000 gelatin capsules; replaced in capsules after exposure to deposits; and held in a darkened room at 65 ± 4 degrees F. and 73 ± 6 percent R.H. where mortality counts were made 72 hours later.

Deposits were prepared by applying the insecticide to the fibreboard blocks with a calibrated pipette.

1/ These insecticides are named according to the approved common names of insecticides published by the Committee on Insecticide Terminology of the Entomological Society of America. Jour. Econ. Ent. 50(2): 226-228.

The test insects were exposed to deposits in groups of ten by placing them in the concavity of a 65 millimeter watch glass; bringing the surface to be tested against the concave face of the watch glass; and inverting the substrate and watch glass as a unit, thus beginning the exposure period. Exposure was terminated by reverting the substrate and watch glass as a unit. In any given test, a preparation of the substrate and exposure of the insects were done at the same times to avoid variations that differing conditions on different days might cause.

Unique methods in the several studies that follow are discussed separately under the appropriate headings.

EFFECT OF DOSE ON STATES OF DEPOSITS

The effect of dose (amount of insectide/unit area) was studied previously (7) but was limited to 4 dose levels (160, 320, 640, and 1,280 mg./ft.$^{-2}$). A wider range and smaller increments of dose were tested to gain more information on the effect of dose levels between and above those previously tested.

MATERIALS AND METHODS

Acetone solutions of DDT, endrin, and dieldrin were applied to fibreboard and the resulting deposits were bioassayed using the standard procedure. Doses of DDT and endrin were tested in the range 320 to 2,560 mg./ft.^{2} in increments of 160 mg. Concentration of the test solution was fixed at 40 mg. insecticide/ml. acetone and dose was increased by increasing the volume of test solution. The volume of solution applied ranged from 0.5 to 4.0 ml., increasing in increments of 0.25 ml. It was not possible to widen this range to get lower and higher doses, because at 0.5 ml. the fibreboard block was barely covered with the solution and at 4.0 ml. the block became saturated and further application led to runoff. If the concentration were increased, the lower dose levels could not be tested since less than 0.5 ml. of solution would be required. If concentration were decreased, the higher dose levels could not be tested since more than 4.0 ml. of solution would be required. This points up the need for other methods of application; a subject discussed later on.

Preliminary tests with dieldrin deposits showed them to be highly toxic at dose levels below 320 mg./ft.^{2} This insecticide was therefore tested at 80 to 640 mg./ft.^{2} in increments of 40 mg. The concentration of the test solution was fixed at 10 mg. dieldrin/ml. acetone.

The sample size in tests of all three insecticides was 10 insects replicated 5 times for each dose level. The deposits were bioassayed at 20 days of age.

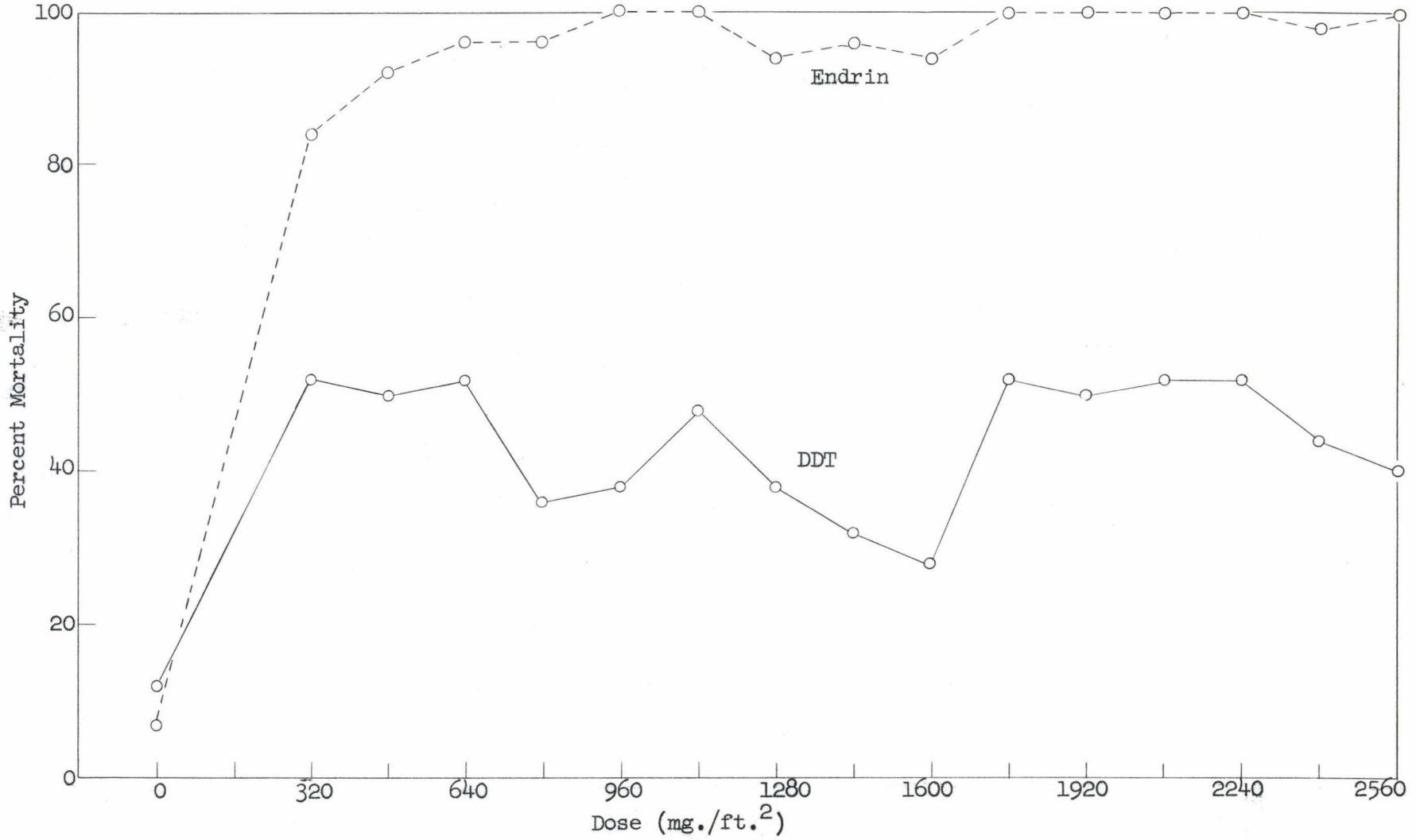


Figure 1.--The effect of dose on mortality of Ips confusus adults exposed to DDT- and endrin-acetone deposits for one minute.

RESULTS

Results with DDT and endrin are shown in figure 1, (tables 1 and 2, appended). The DDT deposits showed no trend of increasing toxicity with increasing dose, mortality varying usually between 30 and 50 percent. Endrin deposits rose steadily in potency, reaching 100 percent mortality.

The deposits of DDT consisted primarily of fine, acicular crystals ranging from 20 to 500μ in length. A light incrustation of very small, granular, mostly amorphous particles formed a background for the needle-like crystals. The crystals were of two kinds: (1) longer border crystals, usually 100 to 500μ long (figure 2A), occurring at the periphery of the patches of incrustation, and (2) shorter crystals, usually 10 or 20 to 50μ long (figure 2B), occurring within the areas of incrustation. Crystal dimension and density[2/] seemed to be unaffected as dose was increased, but coverage [2/] varied directly with dose. Average values for this coverage were estimated visually to be approximately as follows (to the nearest 5 percent):

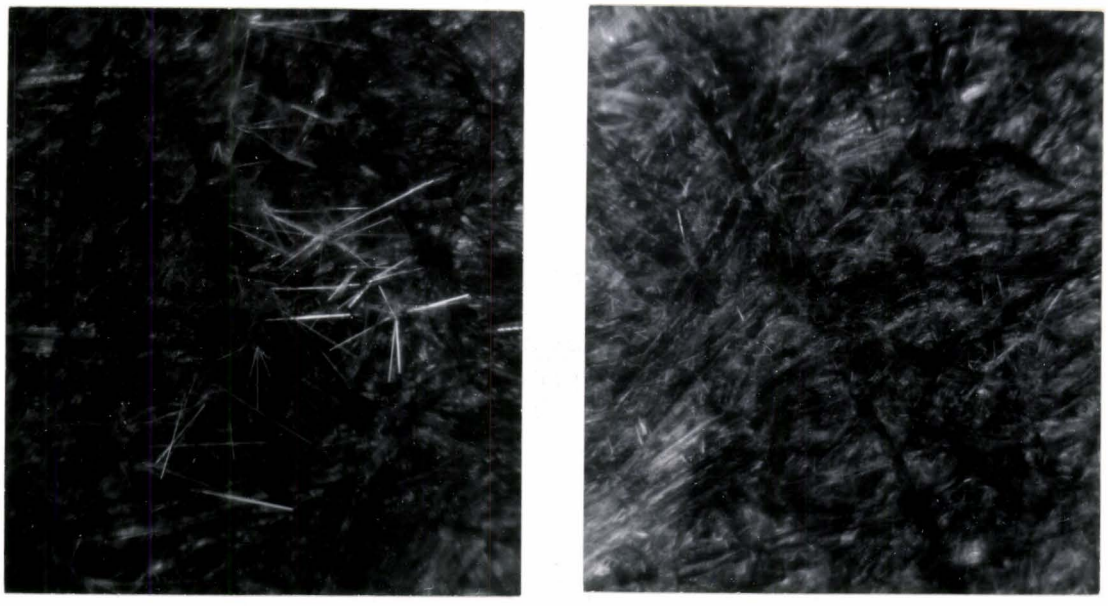
Dose (mg. DDT/ft.^{2})	Coverage (percent)	Mortality (percent)
320	60	52
480	85	50
640	85	52
800-2,560	> 95	42

The deposits of endrin consisted mostly of irregular particles of small size. Some were definitely crystalline having at least one plane surface. Those crystals with regular form were hexagons either with equal sides forming cubes or with rectangular planes. The cubical crystals were generally 10 x 10 x 10μ and those crystals with rectangular planes measured between 5 and 40μ on a side (figure 3).

Crystal dimensions did not seem to change in any way with increasing dose. However, the density of crystals and crystal coverage both increased with dose. Coverage was estimated visually and the averages were as follows:

Dose (mg. DDT/ft.^{2})	Coverage (percent)	Mortality (percent)
320	65	84
480	75	92
640	> 95	96
800	> 95	96
960	> 95	100
1,120-2,560	100	98

2/ Density is defined herein as the number of insecticide particles or crystals per unit area. Coverage is defined as the proportion of a given area that contains insecticide particles. Density thus refers to the closeness of particle spacing whereas coverage refers to the area clothed with particles.



A B

Figure 2.--Acicular crystals of DDT on fibreboard: A - border crystals mostly 100 to 500μ long occurring at periphery of incrustation (54X); B - shorter crystals mostly 20 to 50μ long within area of incrustation (54X).

Figure 3.--Typical endrin deposit on fibreboard made from an acetone solution. The crystals are very small (5 to 40 μ) and granular (54X).

Coverage was high even at the lowest dose and rose rapidly to 100 percent, corresponding closely to the ascending mortality. Increasing mortalities cannot be imputed to increasing coverage alone, however, since density also improved with increasing dose.

Results with dieldrin are shown in figure 4 (table 3, appended). Of the lower seven dose levels, only one showed mortality below 80 percent and of the upper eight dose levels, five showed mortality below 80 percent. Mortality, therefore, tended to fall off, though slightly, with increasing dose.

The deposits of dieldrin were composed chiefly of acicular crystals ranging from 20 to 300μ in length and < 5 to 20μ in width. A very slight incrustation was also present that was similar in appearance to the incrustation occurring in DDT deposits. However, it was so light that the individual particles could not be resolved at 90X magnification. There were no border crystals typical of DDT deposits.

Crystal density and crystal size were unaffected as dose was increased. Coverage, however, fluctuated over a wide range but even so did not have a strong effect on mortality. At a dose of 200 mg./ft.^{2}, coverage was greatest and then decreased at lower and higher dose levels:

Dose (mg. dieldrin/ft.^{2})	Coverage (percent)	Mortality (percent)
80	45	82
120	75	88
160	85	84
200	95	76
240	85	84
280	70	84
320	75	88
360	50	68
400	45	86
440	35	62
480	35	78
520	20	78
560	25	82
600	10	68
640	25	84

When these data above are plotted (figure 5) the effect of coverage on mortality is clearly shown to be slight despite a range of 10 to 90 percent in coverage. The data in figure 5 show a slight trend of increasing mortality with increasing coverage but this would probably not be borne out statistically because of the variability of the data.

DISCUSSION

If mortalities at all dose levels are summed and an average taken for each insecticide the order of increasing mortality was:

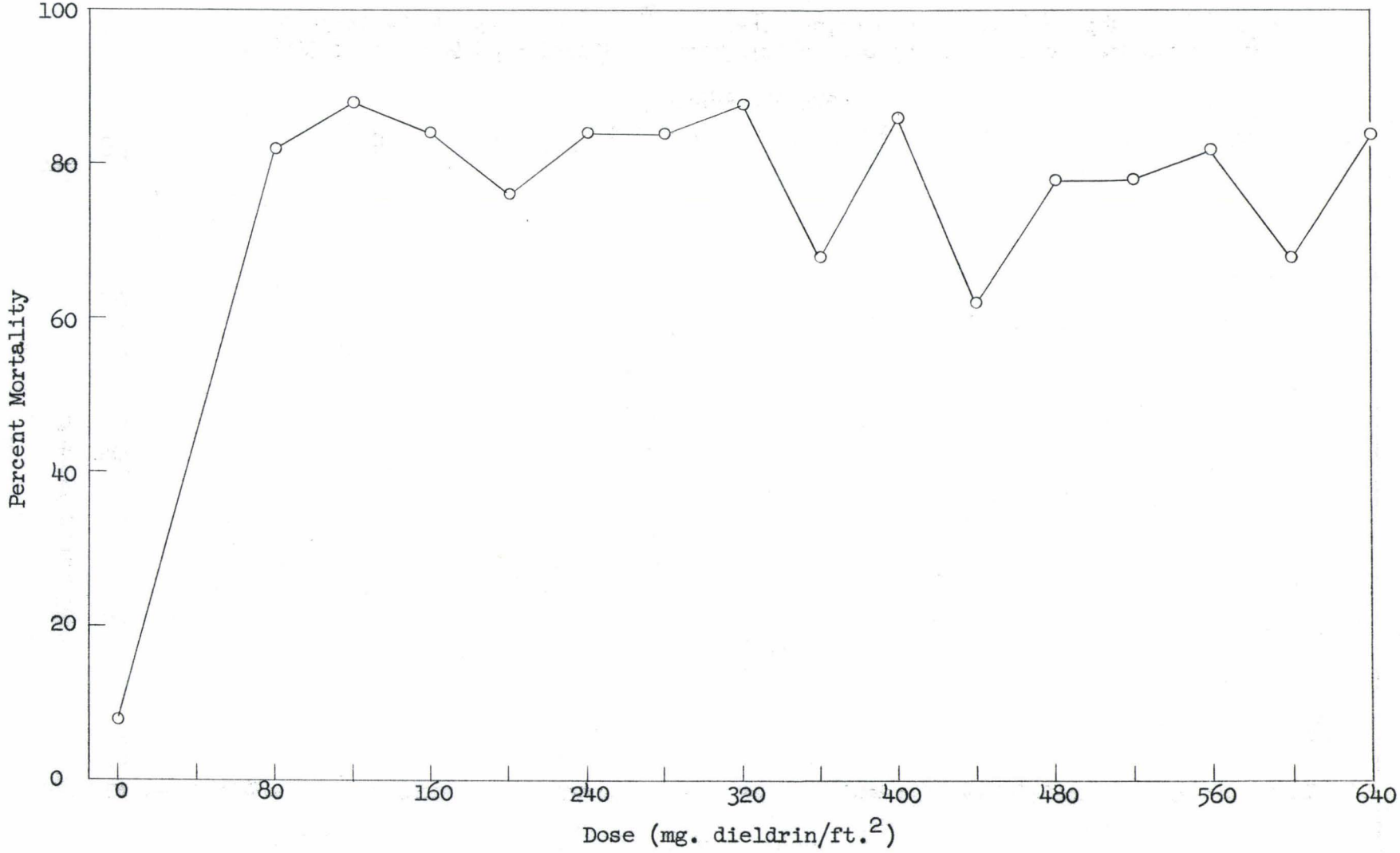


Figure 4.--The effect of dose on mortality of Ips confusus adults exposed to dieldrin-acetone deposits for one minute.

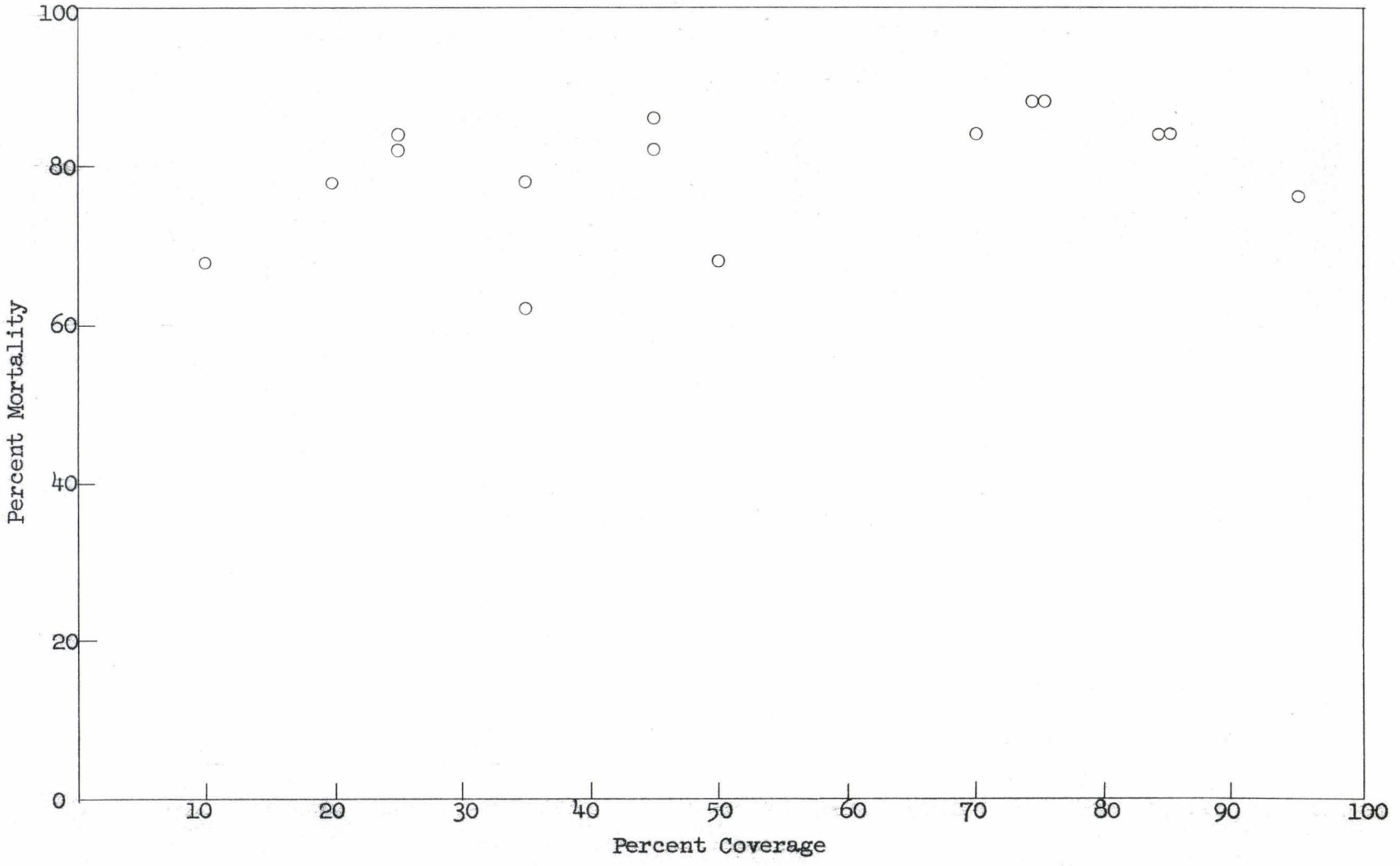


Figure 5.--A plot of coverage of Dieldrin-acetone deposits on fibreboard and the respective mortalities of Ips confusus adults exposed to them for one minute.

DDT (44 percent) < dieldrin (79 percent) < endrin (97 percent). This order of potency is in agreement with studies by topical application to a number of bark beetles including Ips confusus (6,9). The above comparison is not entirely valid since the dieldrin deposits were made from a formulation of lower concentration and were applied at lower dose levels than DDT or endrin. However, the magnitude of differences in toxicity of the three insecticides are great enough to serve as strong evidence that dieldrin is intermediate in potency and that endrin is the most potent with DDT the least.

The effect of dose on mortality showed some striking differences between insecticides. Endrin improved in toxicity with dose, reaching the 100 percent mortality limit. DDT did not change in toxicity throughout the entire range of dose and dieldrin, for all practical purposes, also showed no change in toxicity throughout the full range of dose tested.

An examination of the deposits does not easily reveal the causes of the above mortality trends. Endrin differed from DDT and dieldrin insofar as the deposits showed a progressively more dense crystal growth as the dose level was raised. Like DDT, endrin deposits also showed increased coverage with increasing dose. The cause of increasing mortality of I. confusus adults exposed to endrin deposits of increasing dose could be increasing density, increasing coverage, or more likely both. Important in practical control measures is the fact that endrin can be made more toxic to insects walking over crystalline deposits of this insecticide by increasing the amount applied per unit area.

Interpretation of toxicity of DDT deposits is complicated by the occurrence of two distinct crystal size classes in addition to a granular-type deposit that does not appear to be crystalline. The granular deposit occurs in patches which are usually bounded by long acicular border crystals (100-500μ) and covered sparsely with shorter acicular crystals (20-50μ). Coverage increased with dose, yet mortality was unaffected. When all DDT-acetone deposits from the various tests discussed in this report were arranged according to increasing coverage and plotted with the respective mortalities, the trend of mortality was unaffected throughout most of the range of coverage (figure 6). Mortality rose sharply to about 65 percent as coverage rose to only 5 percent. A further increase in coverage up to about 60 percent did not change mortality. An increase in coverage from 60 percent to 100 percent was followed by a slight drop in mortality until at 100 percent coverage mortality was about 50 percent (compared to about 65 percent at 5 percent coverage). The steep rise in mortality following an increase of from 0 to 5 percent coverage demonstrates the importance of long, needle-like crystals in conferring toxicity, since at a coverage of 5 percent and less the deposit was composed entirely of long (50-300μ), needle-like crystals. Border crystals which are usually 100 to 500μ long occur at the periphery of the patches of incrustation and as these patches become larger (increasing

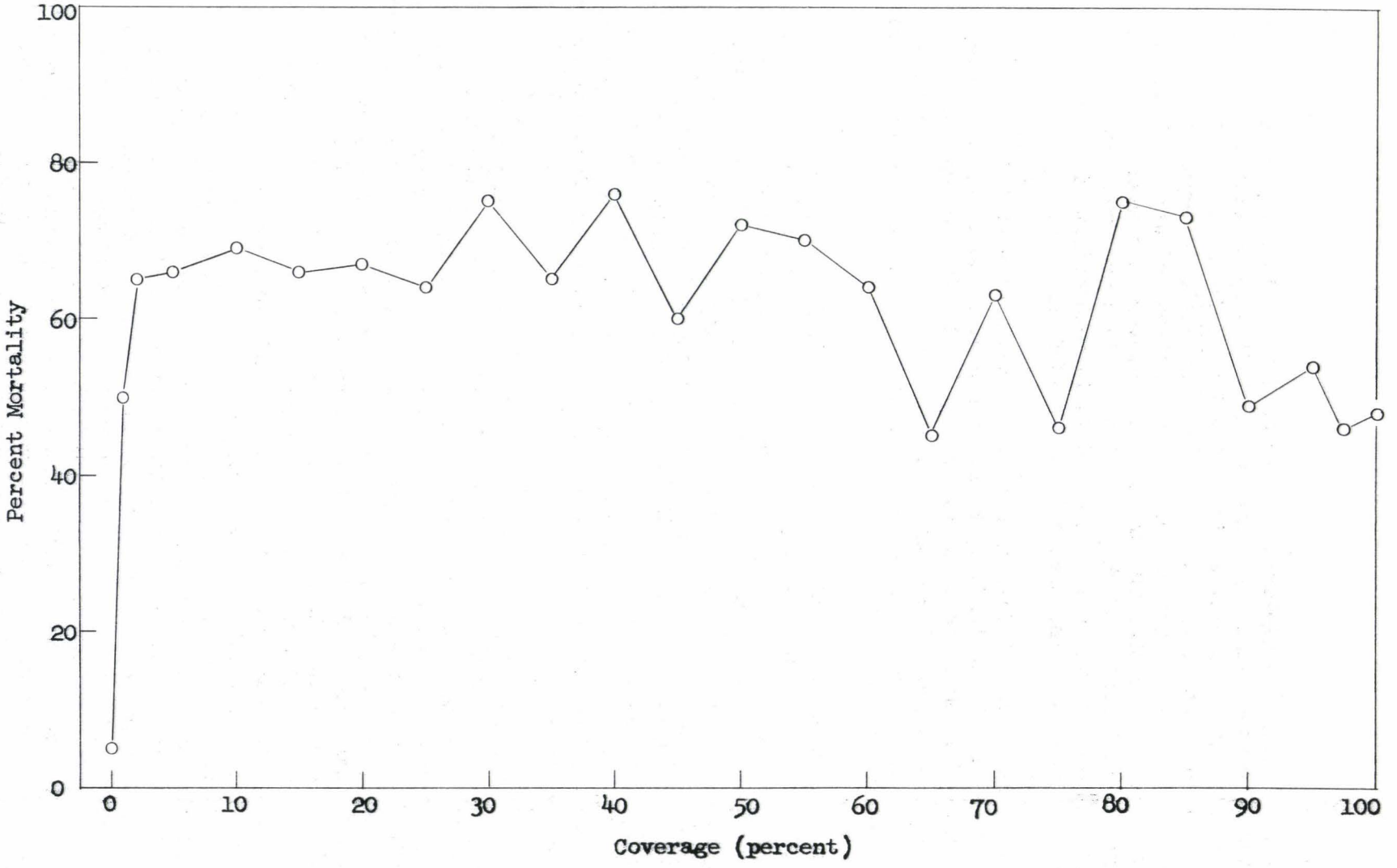


Figure 6.--A plot of coverage of DDT-acetone deposits on fibreboard and the respective mortalities of Ips confusus adults exposed to them for one minute.

coverage) there are fewer and fewer "edges" where border crystals can develop, until at 100 percent coverage border crystals are no longer present. The incrustation itself and the sparse growth of shorter (20-50μ), needle-like crystals within the incrustation area combine to contribute more and more to total toxicity as the border crystals diminish in number. The lesser mortality at the extreme upper limit of coverage therefore represents the combined toxic effects of the shorter crystals plus incrustation, and the higher mortality at the lower extreme of coverage represents the toxic effects of the longer crystals alone. Decreasing mortality above about 50 percent coverage can therefore be imputed to the diminishing occurrence of border crystals.

The effect of dose on mortality of beetles exposed to dieldrin deposits was similar to results with DDT. Mortality was highest at the lowest dose levels and remained unaffected or was slightly reduced as dose was increased.

Crystal structure and density were unaffected as dose was raised. Coverage, however, showed an optimum value at the 200 mg. dose level in contrast to DDT or endrin where coverage increased consistently with dose. Coverage in the dieldrin deposits ranged between about 10 and 90 percent, yet mortality was little affected. Apparently the insects became saturated with dieldrin crystals during their one minute exposure on the deposits of least coverage and deposits of greater coverage were therefore ineffective in augmenting pick-up. Greater differences in mortality within a range of 10 to 90 percent coverage might have been shown with a shorter exposure period. Coverage of less than 10 percent would be necessary to show a distinct reduction in mortality at the one minute exposure period used.

Despite the similarity in chemical structure of dieldrin and endrin, the two insecticides had radically different states of deposits. Dieldrin crystals were acicular and endrin crystals were granular. Dieldrin and DDT were similar though the two insecticides differ greatly in chemical structure. Both dieldrin and DDT deposits contained acicular crystals that were difficult to distinguish except that the dieldrin crystals were generally broader. Dieldrin deposits did not contain the two size classes of crystals nor the heavy incrustation typical of DDT deposits.

EFFECT OF CONCENTRATION ON STATES OF DEPOSITS

A study was begun to find out the effect of concentration (insecticide/carrier ratio) on states of deposits made from solutions. Knowledge of the effects of concentration is important not only in defining the requirements of formulation for practical control work but also in determining the validity of laboratory tests where a given concentration is chosen arbitrarily in the process of evaluating other factors that control states of deposits.

MATERIALS AND METHODS

Studies of concentration effects were limited to work with DDT and dieldrin in acetone solution. The standard bioassay procedure was followed.

Tests were replicated 10 times with DDT deposits and 5 times with dieldrin deposits, giving sample sizes of 100 and 50 beetles, respectively, for each test of a given dose at a given insecticide/carrier ratio.

The effect of concentration was tested by applying the insecticide in two ways: by keeping the volume constant while increasing concentration, and by keeping the concentration constant while increasing the volume applied. Dose levels chosen for each method were the same. The formulation data for the DDT-acetone tests were:

Concentration (mg. DDT/ml. acetone)	Amount applied (ml.)	Dose (mg. DDT/ft.^{2})
	Concentration increasing	
10	1	160
20	1	320
40	1	640
80	1	1,280
	Concentration constant	
20	0.5	160
20	1	320
20	2	640
20	4	1,280

The formulation data for the dieldrin-acetone tests were:

Concentration (mg. dieldrin/ml. acetone)	Amount applied (ml.)	Dose (mg.dieldrin/ft.^{2})
	Concentration increasing	
5	1	80
10	1	160
20	1	320
40	1	640
	Concentration constant	
10	0.5	80
10	1	160
10	2	320
10	4	640

A lower series of doses was tested for dieldrin because exploratory tests had shown this insecticide to be toxic even at relatively low rates of application.

Dieldrin deposits were tested at one month of age and DDT deposits at two months.

RESULTS WITH DDT DEPOSITS

Figure 7 (table 4, appended) shows that the effect of concentration was slight in tests with DDT-acetone solutions. There were no significant differences in mean mortalities at the 160, 320, and 1,280 mg. dose levels whether concentration was fixed or increased geometrically. The 640 mg. dose level was an exception. A t-test ($t=2.84$; $d.f.=18$) gave a probability of less than 2 percent that the difference between mean mortalities was due to chance.

The deposits were virtually identical at a given dose whether concentration was fixed or was increased geometrically. Even at the 640 mg. dose where mortality was significantly different, no differences in the deposits could be detected. Coverage was estimated visually to be as follows:

Dose (mg. DDT/ft.^{2})	Approximate coverage (percent)
160	< 5
320	25
640	95
1,280	95

The crystals were acicular, ranging from 20 to 500 or 600μ long. Most were fine and about 5μ wide and a few were up to 20μ wide. They occurred in two distinct size classes. One class was composed of mostly 100 to 600μ crystals occupying the edges of incrusted areas. The second class of crystals were usually 20 to 50μ long and occurred mostly within the incrusted areas. The exact nature of the incrustration could not be resolved with a dissecting scope at 90X.

RESULTS WITH DIELDRIN DEPOSITS

Figure 8 (table 5, appended) shows a marked effect of concentration on dieldrin-acetone deposits. When the concentration was fixed and dose was increased by applying increasing volumes, the 80, 160, 320, and 640 mg. deposits were equal in toxicity, killing about 85 percent of the beetles. When concentration was doubled for each increment of dose, mortality was optimum at a dose of 160 mg. dieldrin/ft.^{2}

An examination of states of deposits explains the effect of concentration. Crystal structure was indistinguishable from that of DDT deposits. The preponderance of crystal growth was in the form of needle-like or acicular crystals (figure 9). There was also a slight incrustation. The crystals were similar in structure whether concentration was fixed or increased: 20 to 300μ long, but mostly 50 to 150μ, and from < 5 to 15 or 20μ wide. However, coverage differed between a fixed and increasing concentration, as shown in table 6.

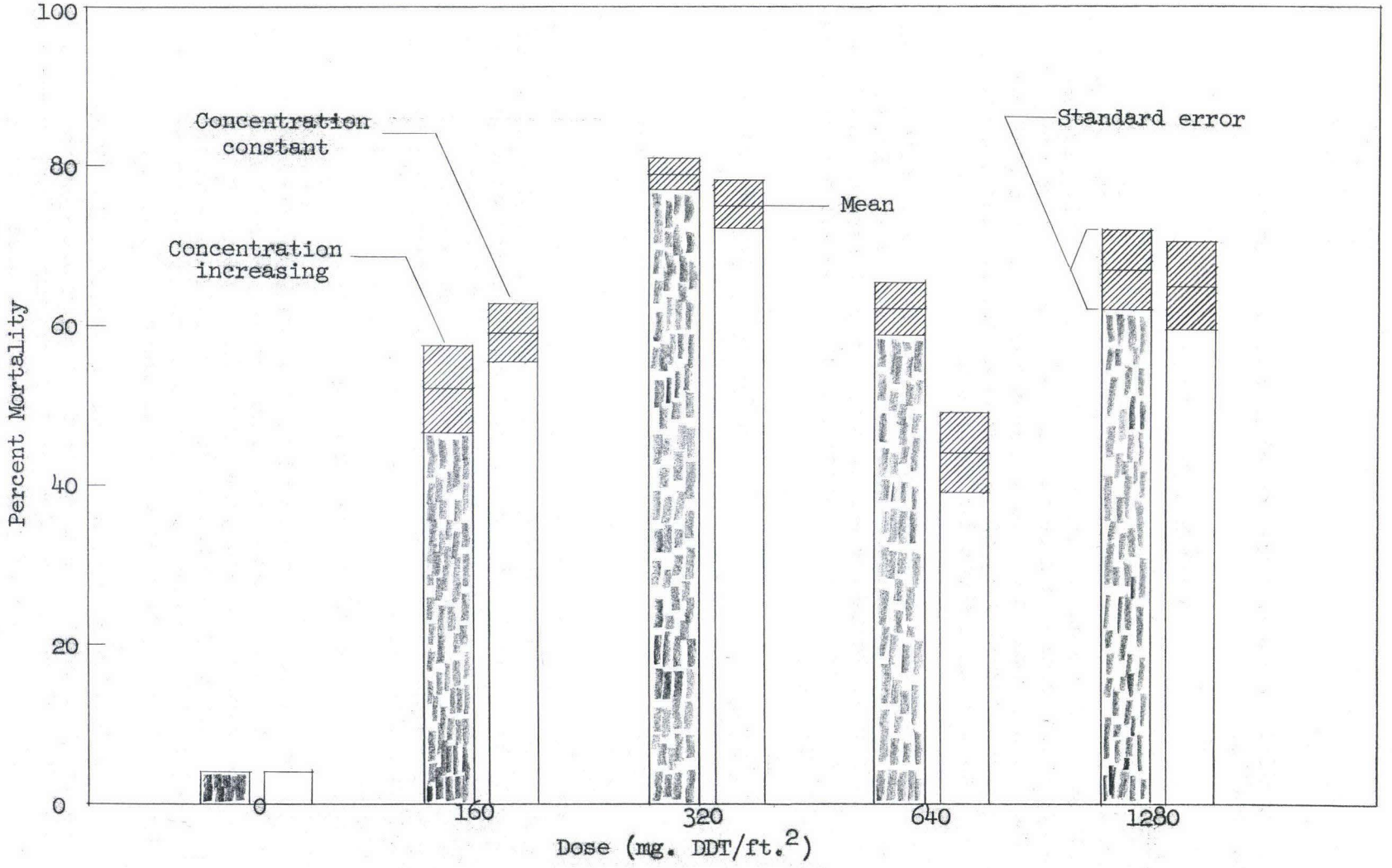


Figure 7.--The influence of concentration on mortality of Ips confusus adults exposed to DDT-acetone deposits for one minute.

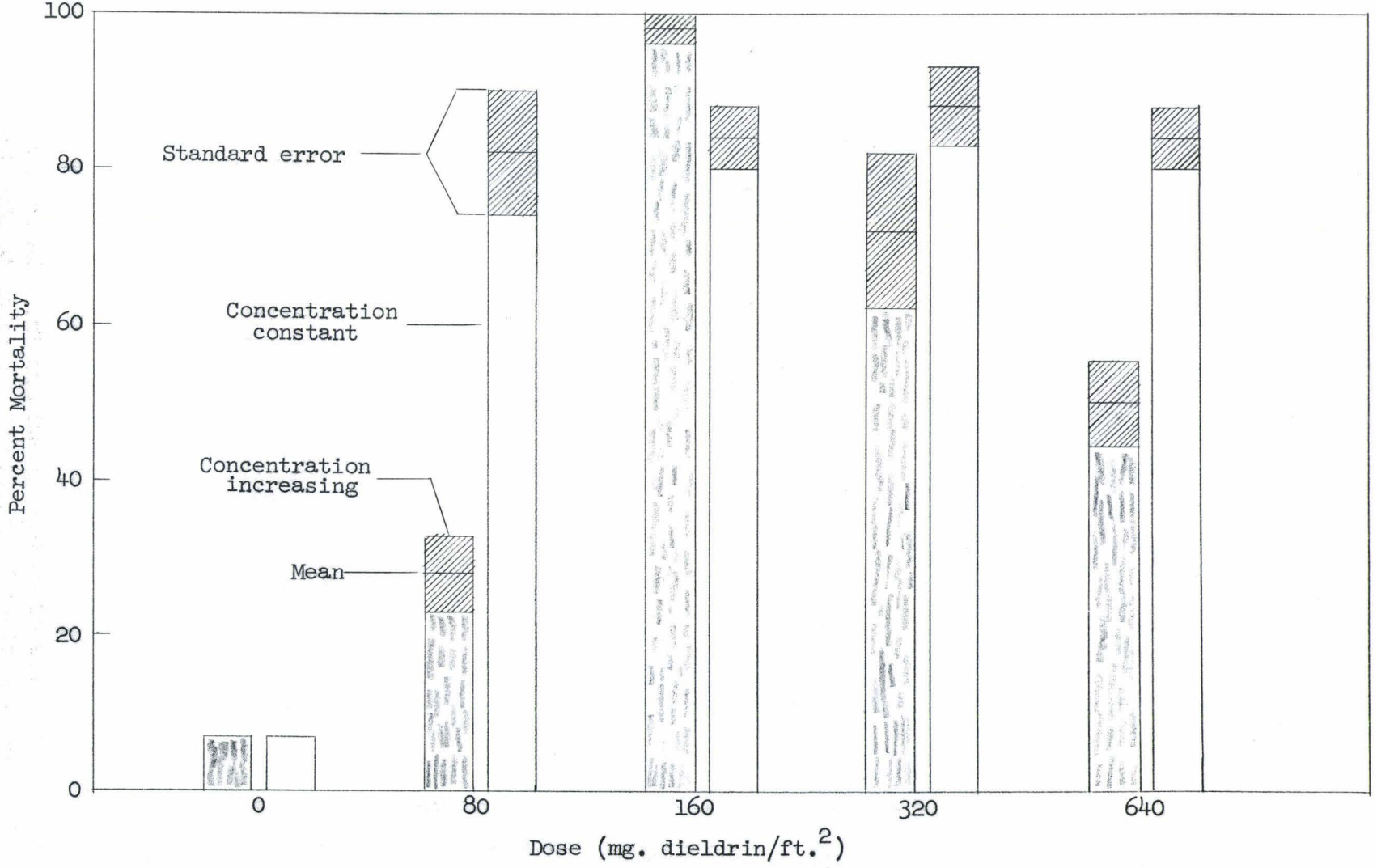


Figure 8.--The influence of concentration on mortality of Ips confusus adults exposed to dieldrin-acetone deposits for one minute.

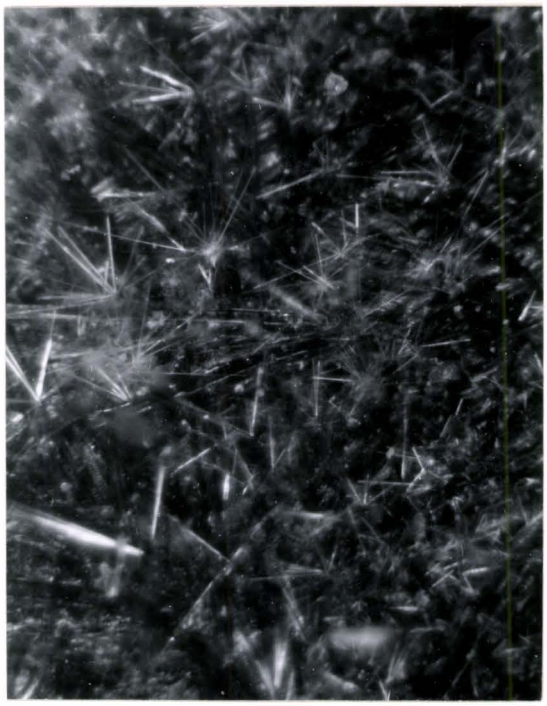


Figure 9.--Crystals of dieldrin resulting from the application of acetone solutions to fibreboard. Similar to DDT, they frequently arose from a common point forming clusters (54X).

Table 6.--The effect of concentration on coverage in dieldrin deposits

Dose	Concentration	Coverage	Mortality and standard error
mg.dieldrin/ft.^{2}	mg. dieldrin/ml.acetone	percent	percent
	Concentration increasing		
80	5	< 5	28 ± 5
160	10	85	98 ± 2
320	20	80	72 ± 10
640	40	< 5	50 ± 5
	Concentration constant		
80	10	45	82 ± 8
160	10	85	84 ± 4
320	10	75	88 ± 5
640	10	25	84 ± 4

When concentration was fixed, therefore, coverage ranged widely with increasing dose though not as much as it did when concentration was increased in proportion to dose. It can be seen that the differences in coverage where concentration was fixed were not great enough to affect mortality. However, coverage ranged widely enough to show significant effects on mortality when concentration was increased proportionally with dose. At doses of 80 mg. and 640 mg., coverage was reduced to less than 5 percent, resulting in lower mortalities than those obtained with doses of 160 and 320 mg.

DISCUSSION

The effect of concentration on states of deposits was by no means clearly defined by this limited study. The approach used was to increase concentration proportionally to dose on the one hand and increase dose without changing concentration on the other. More information can be had if a series of concentrations are studied at each of several dose levels; this is planned in future studies.

The deposits of DDT were shown to be generally unaffected by concentration within the limits studied. At a dose level of 640 mg./ft.^{2} a statistical difference in mortality was obtained but since no differences could be detected in the deposits, the difference in mortality was probably due to experimental error.

On the other hand, dieldrin deposits were strongly affected by concentration. Even as dose was increased from 80 to 640 mg. in increments of 80 mg., mortality was unchanged when concentration was fixed at a constant value. As concentration and dose were increased

proportionally, mortality was optimum at 160 mg. and decreased significantly above and below this level of dose.

The important influence of concentration in the studies of dieldrin deposits was shown to be exerted on crystal coverage and not structure or density. However, coverage can vary over a wide range before differences show up in mortality estimates. For instance, in the test with a fixed concentration, coverage varied from about 25 percent to about 85 percent, yet mortality was unchanged, remaining at about 85 percent. In the tests where concentration and dose were increased proportionally, coverage was well below 5 percent at the 80 and 640 mg. dose levels, low enough to show a strong effect on mortality.

Note also in table 6 that dose had some influence on coverage. Where concentration was fixed at a constant value, coverage varied from 25 to 85 percent depending on dose. In the tests with DDT, coverage was determined solely by dose and concentration was uninfluential. Whether concentration was fixed at a constant value or was increased at the same rate as dose, coverage was < 5, 25, 95, and 95 percent corresponding to doses of 160, 320, 640, and 1,280 mg. DDT, respectively.

EFFECT OF SUNLIGHT ON STATES OF DEPOSITS

The duration and intensity of sunlight striking treated logs will undoubtedly govern, in large part, the useful life of the insecticide deposits thereon. Sunlight may also influence the development of deposits so that characteristic deposit formations in the laboratory may not represent actual conditions encountered in a field control program. For these reasons, tests were begun to circumscribe some of the important effects of sunlight on the states of deposits of residual-type insecticides.

MATERIALS AND METHODS

Tests were done with DDT-acetone solutions and the standard bioassay procedure was used. To evaluate the effect of solar radiation, the deposits were held outdoors on tables in an area receiving 6 to 8 hours of unobstructed sunlight daily (figure 10). Some blocks were laid flat to simulate the exposure to which the upper surface of fallen logs would be subjected. Other blocks were held vertically to simulate the exposure received by the sides of a fallen log or by a standing tree. Some of these blocks were oriented to face east, others south. These two cardinal directions provided more intense exposure than a west or north orientation. Finally, to simulate deep shade, samples of treated blocks were completely withheld from exposure to sunlight by keeping them on shelves in a closed but well ventilated building. Thus, four degrees of exposure were created: deep shade or no exposure; east-facing exposure receiving 3 to 4 hours

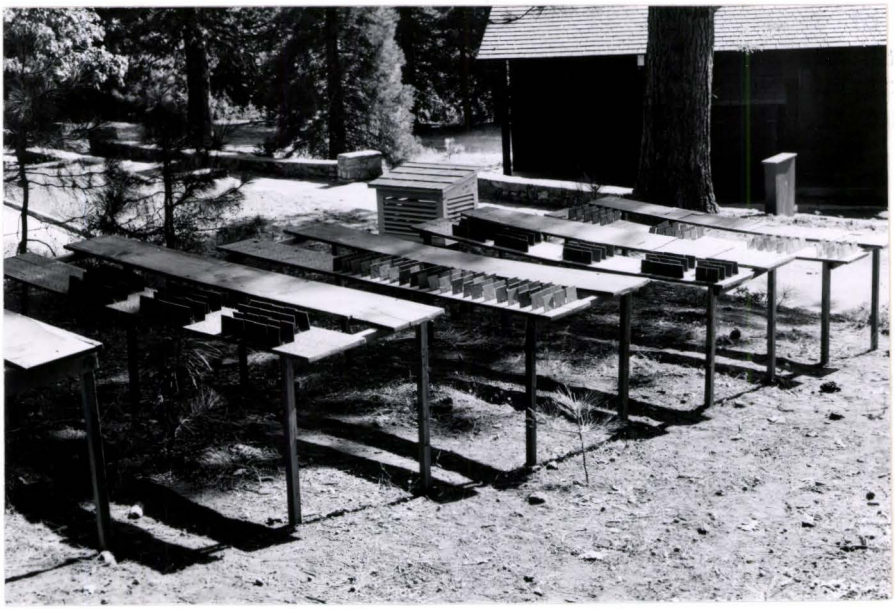


Figure 10.--Fibreboard blocks treated with DDT-acetone solutions being exposed to solar radiation.

of direct sunlight, mostly at a low angle of incidence except for the cooler sun of the early morning; south-facing exposure receiving 6 to 8 hours of direct sunlight at a low angle of incidence; and maximum exposure (horizontal blocks) receiving 6 to 8 hours of sunlight, mostly at a high angle of incidence.

Samples of the treated blocks were bioassayed after one month and after two and one-half months of exposure. The sample size was 10 insects replicated 10 times in tests of the 1-month-old deposits and 10 insects replicated 5 times in tests of the $2\frac{1}{2}$-month-old deposits.

After the deposits had aged for about two weeks, a moderate 20-minute rain fell and the treated blocks were noted to absorb much of the water that fell upon them. This soaking probably did not have a strong effect on the development of the deposits since investigations on the effects of moisture content of the fibreboard substrate on states of deposits, discussed in another part of this report, showed that a high moisture content was ineffectual in altering the deposit. However, it has been shown that DDT crystallizes upon mechanical stimulation and the impact of rain drops may have acted as a mechanical stimulus. Rainfall may also dislodge crystals and tend to reduce the toxicity of the deposits.

RESULTS

Results of the 1-month and $2\frac{1}{2}$-month bioassays are shown in figure 11 (tables 7 and 8, appended). The standard error is indicated by vertical bars extending above and below the mean. The data of figure 11 show that exposure to solar radiation has a profound effect on the toxicity of the deposits. Considering first the one-month tests on the left in figure 11, an important relationship is shown. Deposits of 320 mg. DDT/ft.^{2} were clearly more toxic when they received intermediate levels of solar radiation, i.e., when the fibreboard blocks were held vertically and oriented east and south. Results with deposits of 640 mg. were similar except that toxicity did not differ between the south-facing and horizontal tests. The heaviest deposits of 1,280 mg. differed sharply by showing consistently greater toxicity as the degree of exposure to sunlight was increased.

Results with the $2\frac{1}{2}$-month test (figure 11) were similar to the 1-month tests but the 1,280 mg. dose did not show the same consistent improvement in efficiency as the degree of exposure was increased. The $2\frac{1}{2}$-month deposits tended to be more toxic. This cannot be explained by improvement in the deposits. It is more likely due to a greater susceptibility in the beetle population used to bioassay the $2\frac{1}{2}$-month deposits or due to changing temperature conditions which are known to influence the toxic action of insecticides.

The data of figure 11 were rearranged with dose along the abscissa to show the interrelations of dose and exposure to solar

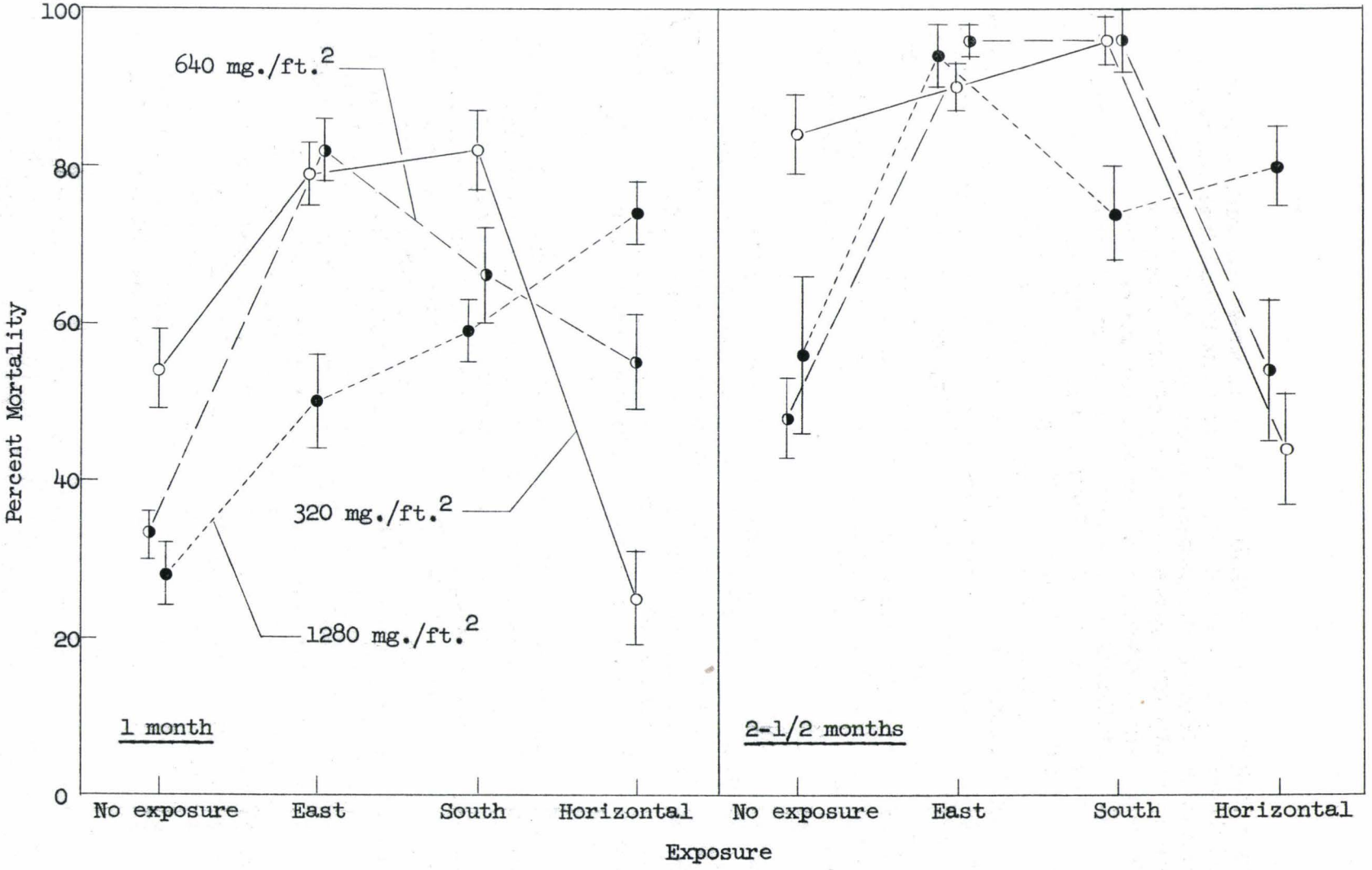


Figure 11.--Mortality of Ips confusus adults exposed for one minute to 1-month and 2 1/2-month-old DDT-acetone deposits subjected to varying amounts of solar radiation.

radiation (figure 12). Several points of interest are brought out by the 1-month data in figure 12. The deposits withheld from exposure to solar radiation showed the greatest toxicity at the 320 mg. dose level. This relationship corresponds to results of laboratory tests where the deposits were also withheld from exposure to forces of the outside environment. With intermediate exposure, i.e., vertical blocks facing east and south, greater toxicity was shown either by the lowest dose (320 mg./ft.^{2}) or by the two lowest doses (320 and 640 mg./ft.^{2}). The relationship between dose and exposure was clearly reversed by the deposits that received maximum sunlight, i.e., blocks held horizontally. These deposits were progressively more toxic as dose was raised. Therefore, under conditions of no exposure to sunlight, toxicity was decreased as dose was increased. Under conditions of intermediate exposure (east- and south-facing blocks) toxicity also tended to fall as dose was increased. Finally, under conditions of maximum exposure (horizontal blocks) the toxicity trend was reversed, rising instead of falling with increasing dose.

Consequently, the tests of one-month-old deposits showed that the optimum dose of the series of doses tested depended on the amount of solar radiation received by the developing deposits. Tests of $2\frac{1}{2}$-month-old deposits gave similar results except that the toxicity of the deposits receiving intermediate amounts of sunlight (vertical blocks facing east and south) either remained the same or decreased with increasing dose.

Further examination of the one-month data of figure 12 shows that regardless of dose the deposits that received an intermediate amount of sunlight were always more toxic than the deposits that were not exposed to sunlight. These data suggest that somewhat less than maximum sunlight is actually beneficial to DDT-acetone deposits on fibreboard for doses of 320, 640, and 1,280 mg./ft.^{2} This is true for the deposits that were one month old only, because the data for the $2\frac{1}{2}$-month-old deposits in figure 12 show that $2\frac{1}{2}$ months of exposure to sunlight began to affect the toxicity of the deposits adversely. After this prolonged exposure period the differences in toxicity were much less at the 320 and 1,280 mg. dose levels. Some exposure to intermediate amounts of sunlight improved toxicity therefore, but under prolonged exposure the advantage gained was being erased through deterioration of the deposits by the action of solar radiation. The converse, improvement in toxicity of the deposits not exposed to sunlight is unlikely because no detectable change in the states of these deposits was visible beyond one month of aging.

The comparison of mortality curves obtained by bioassay of deposits receiving maximum sunlight (horizontal) and no sunlight (no exposure) in figure 12 brings out another important relationship. Data for the one-month-old deposits show the deposits receiving maximum sunlight to be more toxic than the deposits receiving no sunlight at the 640 and 1,280 mg. dose levels. But, at the 320 mg. dose level,

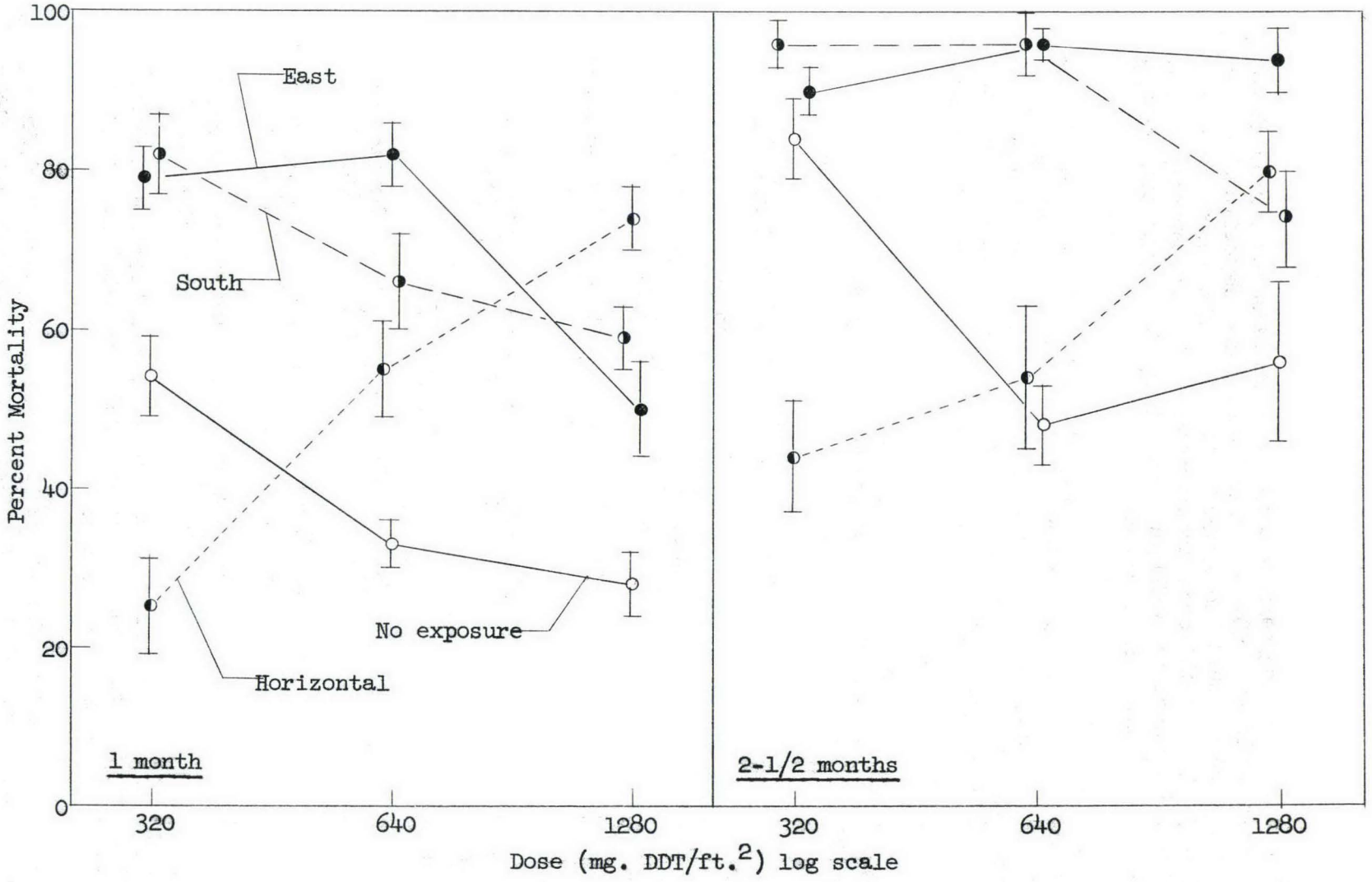


Figure 12.--Mortality of Ips confusus adults exposed for one minute to 1-month and 2 1/2-month-old DDT-acetone deposits subjected to varying amounts of solar radiation.

the deposits receiving maximum sunlight were less toxic than those that received no sunlight. The data for $2\frac{1}{2}$-month-old deposits showed similar results except that the toxicity of the blocks receiving maximum sunlight dropped at all dose levels relative to the toxicity of the deposits not exposed to sunlight. This indicates again that sunlight exerts a deleterious effect as well.

The conclusion is that maximum sunlight was beneficial to the heavier deposits (640 and 1,280 mg.) at one month and the heaviest deposit (1,280 mg.) at $2\frac{1}{2}$ months exposure if toxicities are compared to those resulting from bioassay of deposits not exposed to sunlight. And the beneficial effects of sunlight tended to be nullified through prolonged exposure.

The interrelationship of sunlight and dose are shown by arranging the different degrees of exposure in a decreasing order corresponding to the decreasing order of potency of the respective deposits.

Dose	Degree of exposure and mortality ± S.E.
	At 1 month
320	south = east > no exposure > horizontal (82±5) (79±4) (54 ± 5) (25 ± 6)
640	east > south = horizontal > no exposure (82±4) (66±6) (55 ± 6) (33 ± 3)
1,280	horizontal > south = east > no exposure (74 ± 4) (59±4) (50±6) (28 ± 4)
	At $2\frac{1}{2}$ months
320	south = east = no exposure > horizontal (96±3) (90±3) (84±5) (44 ± 7)
640	south = east > horizontal = no exposure (96 ±4) (96±3) (54 ± 9) (48 ± 5)
1,280	east > horizontal = south > no exposure (94±4) (80 ± 5) (74±6) (56 ± 10)

Here it is shown more clearly that the beneficial effects of sunlight depend on its duration and intensity and that the effect is different at different dose levels.

An examination of the states of deposits helps to explain some of the results of the tests. It was immediately apparent that environmental factors exert a profound effect on deposit structure. Those deposits withheld from exposure to sunlight were typical of DDT deposits in laboratory tests. They were composed of the particulate incrustation

and acicular crystal growth. The crystals were of two classes, border crystals usually 100 to 500μ long, reaching 600μ, bounding the irregular patches of incrustation, and shorter acicular crystals usually 50μ long, ranging from 10 to 150μ, occurring within areas of incrustation.

Those deposits exposed to the environment were remarkably different (figure 13). An incrustation was, for all practical purposes, absent. Very rarely, a minute patch of incrustation was seen but it never amounted to an appreciable deposit. The crystals were long, acicular, very dense, and of one size class unlike deposits withheld from exposure to sunlight. The crystals were usually 100 to 300μ in length and ranged from 50 to 800μ. They were usually 5 to 10μ wide but many, even on a given fibreboard block, were so fine ($< 5\mu$) as to impart a fuzzy appearance to the substrate. The separate crystals were difficult or impossible to distinguish individually. The fine crystals were also frequently matted, which was probably due to the action of wind currents and the action of miscellaneous insects visiting them. All blocks held outdoors and especially those held horizontally, contained much pollen, sand, and miscellaneous debris.

The degree of exposure to solar radiation produced only slight differences in crystal structure and density. This was not true of course between deposits exposed to sunlight as a group and deposits withheld from sunlight; the latter possessed quite different crystal structure from the former. The deposits not exposed to sunlight had long acicular crystals only at the boundaries of patches of incrustation. As the area of incrustation increased, the combined length of these boundaries per fibreboard block decreased so that the total mass of long border crystals, of necessity, also decreased. This in part may explain the toxicity differences between the deposits receiving no exposure and those exposed to sunlight. In effect, the toxicity differences are the indirect result of changes in coverage since a change in coverage on those blocks not exposed to sunlight decreased the proportion of long acicular crystals. Those deposits exposed to sunlight were generally more toxic because they were composed entirely of long acicular crystals and these were more toxic than shorter ones as indicated by the drop in toxicity as coverage increased and the proportion of short crystals increased on deposits that received no sunlight.

Coverage, therefore, occupies a central role in explaining toxicity differences between the various tests and, in fact, coverage was by far the largest variable in the states of deposits. Table 9 presents approximate estimates of coverage along with corresponding mortalities for the various tests of 1- and $2\frac{1}{2}$-month-old deposits. However, the data in table 9 show that, among those blocks exposed to sunlight, the effect of coverage was not critical except at its lower limits. Figure 14 is a plot of coverage and respective mortalities obtained from all the data on those deposits exposed to the environment. Mortality rose sharply from 0 to about 20 percent coverage and changed little through the remaining increments of coverage.

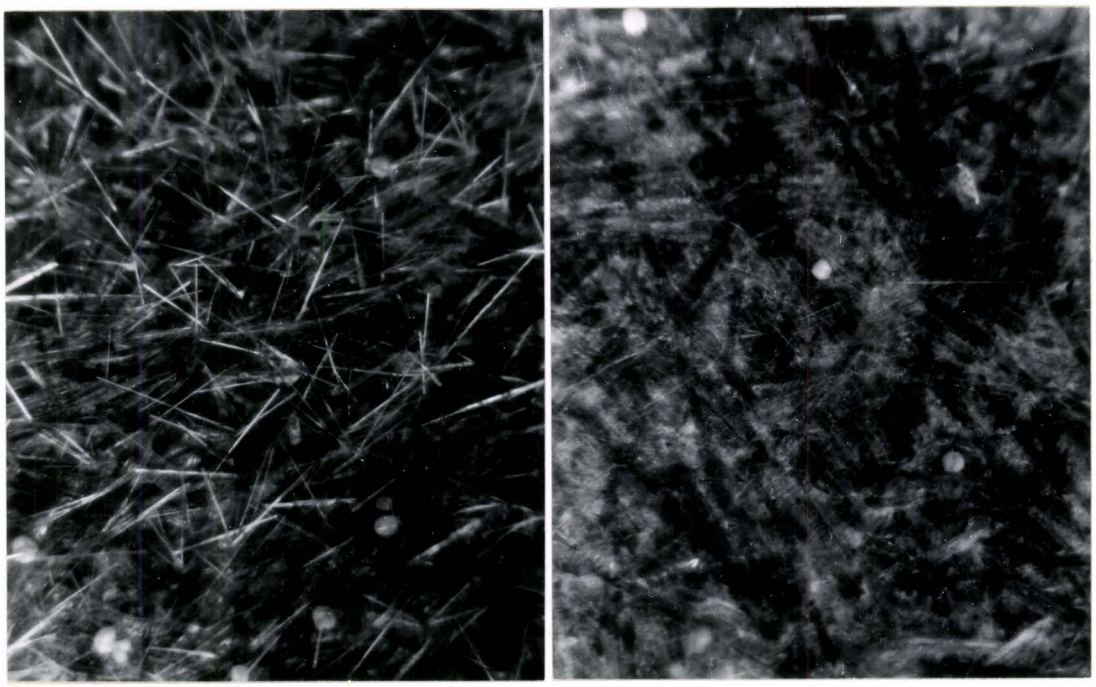


Figure 13.--Typical DDT crystals on fibreboard exposed to the environment: Left - stouter crystals usually 5 to 10 μ wide; Right - finer crystals less than 5 μ wide. The two types of crystals occurred regularly on the same fibreboard block. The fine ones on the right were extremely dense but being so fine they are difficult to identify individually and they impart a fuzzy appearance to the substrate (54X).

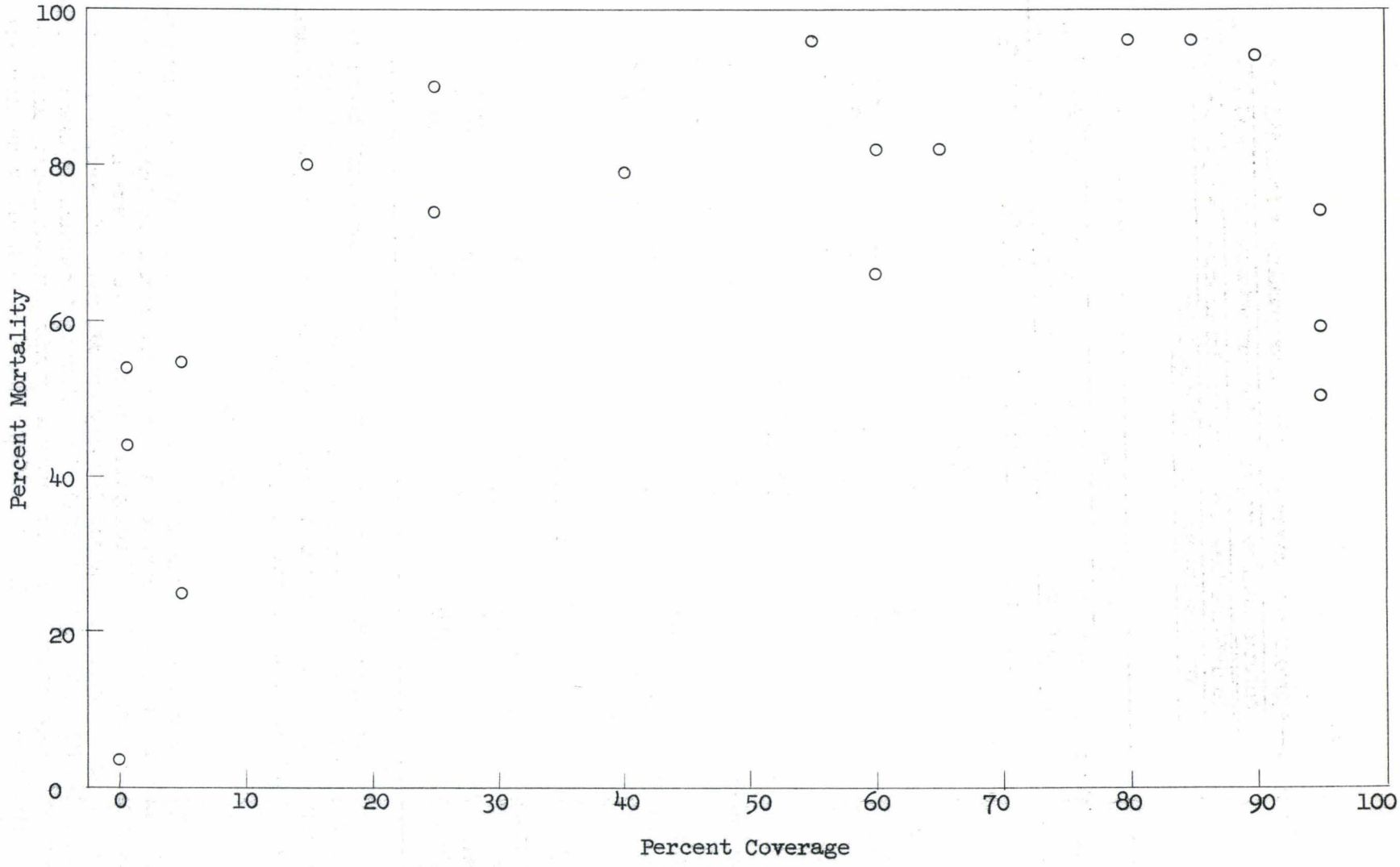


Figure 14.--A plot of coverage of DDT-acetone deposits exposed to sunlight and the respective mortalities of Ips confusus adults exposed to them for one minute.

Table 9.--Approximate coverage and corresponding mortalities of Ips confusus adults exposed for one minute to 1- and 2½-month-old DDT-acetone deposits at three dose levels subjected to various intensities of sunlight

Exposure	1-month deposits		2½-month deposits	
	Approx. coverage	Mortality ± S.E.	Approx. coverage	Mortality ± S.E.
	Percent	Percent	Percent	Percent
		320 mg. dose		
No exposure	15	54 ± 5	20	84 ± 5
East	40	79 ± 4	25	90 ± 3
South	65	82 ± 5	55	96 ± 3
Horizontal	< 5	25 ± 6	< 1	44 ± 7
		640 mg. dose		
No exposure	> 95	33 ± 3	> 95	48 ± 5
East	60	82 ± 4	80	96 ± 2
South	60	66 ± 6	85	96 ± 4
Horizontal	5	55 ± 6	< 1	54 ± 9
		1,280 mg. dose		
No exposure	> 95	28 ± 4	> 95	56 ± 10
East	95	50 ± 6	90	94 ± 4
South	95	59 ± 4	95	74 ± 6
Horizontal	25	74 ± 4	15	80 ± 5

Therefore, the major effect of the environment on states of deposits was reflected in crystal structure and coverage, but the important variable in deposits exposed to some degree of sunlight (this excludes deposits not exposed to sunlight) was coverage.

DISCUSSION

In these tests of the effect of environment it should be recognized that the actual forces of the total environment directly responsible for controlling the development of the deposits are not known. Since crystal growth may depend largely on the rate of evaporation of the carrier (2) it is likely that the major environmental forces acting to control evaporation and thus crystal growth are sunlight, temperature, wind velocity, and humidity. The role of each of those factors needs study before quantitative estimates of their individual effect on deposits can be made. However, temperature is probably the most

important factor controlling evaporation. The ambient air temperature and direct radiation from the sun both contribute to the temperature of the fibreboard blocks during the day and the air temperature alone at night. Radiation from the sun may raise the temperature of the substrate considerably above the ambient air temperature and thus may play a leading role in evaporation and concurrently in crystal growth. Solar radiation also decomposes DDT (2) and thus exerts both favorable and unfavorable effects. There may be still further effects of solar radiation that are unknown.

The average maximum and minimum temperatures outdoors (by hygrothermograph recordings) during the tests were 81 and 57 degrees F., respectively. Those blocks sheltered from sunlight were exposed to average maximum and minimum temperatures of 79 and 64 degrees F., respectively. The similarity of these temperatures suggests that differences in temperature of the substrates exposed and sheltered from sunlight were due principally to radiation. Therefore, solar radiation should be mainly responsible for differences in evaporation from the sheltered and exposed substrates and concurrently for differences in crystal growth.

The average maximum and minimum relative humidities outdoors were 76 and 40 percent, respectively. The blocks sheltered from sunlight were exposed to average maximum and minimum relative humidities of 60 and 44 percent, respectively. These comparatively small differences in relative humidity were probably subordinate to temperature differences in their effects on the deposits.

Results of studies of environmental factors have shown that some sunlight was beneficial to deposits at all three dose levels (320, 640, and 1,280 mg. DDT/ft.^{2}), mortality being higher in those beetles exposed to deposits receiving the sunlight than in those sheltered from sun. Under conditions of maximum intensity, sunlight was beneficial to the deposits at the two highest dose levels (640 and 1,280 mg.) but detrimental to the deposits at the lowest dose level (320 mg.). A generalized picture of the effects of exposure to sunlight on toxicity of deposits is shown by the following decreasing order of effectiveness at the three dose levels:

320 mg.:

intermediate > shade > maximum

640 mg.:

intermediate > maximum > shade

1,280 mg.:

Maximum > intermediate > shade

"Intermediate" represents the combined results from vertical blocks outdoors facing east and south; "shade" represents blocks sheltered from sunlight; and "maximum" represents blocks held horizontally outdoors. The above arrangement allows the generalization that deposits of lighter dose can be improved in toxicity with moderate amounts of sunlight and that intense sunlight will actually reduce toxicity. Deposits of heavier dose can be subjected to more intense sunlight without impairing toxicity and, in fact, the deposits of heaviest dose (1,280 mg.) were most toxic when exposed to maximum sunlight.

These conclusions are drawn from tests at one point in time, i.e., after one month of exposure to the environment. Sunlight has two important characteristics influencial in affecting the states of deposits and these are duration and intensity. No information has been gained on the effects of less than one month's exposure. Exposures of two and one-half months were also made and the results from these tests indicate that the detrimental effects of sunlight are appearing at least by this time. On the basis of these tests, therefore, sunlight may not be detrimental to DDT deposits, if dose is heavy enough, over the period of time covering an emergence period of a beetle population and, in fact, some improvement in the efficiency of the deposit might be expected under some conditions.

Considering only those deposits subjected to varying intensities of sunlight, the major differences in deposit structure were expressed in the coverage of crystals over the surface of the substrate. Crystal size and shape and crystal density were little affected. Even though coverage was the largest variable (varying from < 1 to 100 percent), changes in coverage were relatively ineffective in producing changes in toxicity except at the extreme lower limits. Toxicity rose steeply from 0 to about 20 percent coverage and remained stable, though became more variable, as coverage increased to > 95 percent. The reason for this is speculative but very likely due to the saturation of the insect with insecticide crystals at coverages of 20 percent and above. At about 20 percent coverage an equilibrium is reached between the number of crystals picked up and the number detached, with the one-minute exposure period used in these tests. This equilibrium was not yet reached with deposits of less than 20 percent coverage. Coverage of better than 20 percent were ineffective in improving toxicity because the capacity for picking up insecticides of a given state is fixed and a 20 percent coverage permitted maximum pick-up in a one-minute contact period.

EFFECT OF MOISTURE CONTENT OF SUBSTRATE ON STATES OF DEPOSITS

The percent moisture content of the fibreboard substrate changes with changes in humidity. The variable nature of deposits

on fibreboard led to the suspicion that differences in moisture content of the substrate at the time insecticides were applied to it might be responsible for some of the variation in states of deposits. A study was begun to find out if changes in moisture content, greater than those changes normally induced by daily fluctuations in relative humidity, would be critical enough to induce significant variations in the states of deposits and in mortality of the test beetles.

MATERIALS AND METHODS

The tests were conducted with DDT-acetone and DDT-xylene solutions applied to fibreboard. The solvents acetone and xylene are soluble in water in all proportions and insoluble in water, respectively. These two solvents, therefore, represent the extremes in water solubility. It was felt that if water solubility of the carrier influenced the development of deposits on dry versus moist substrates then tests of carriers differing widely in water solubility would be essential to the studies.

The standard bioassay technique was used. The adult beetles were exposed in groups of 10 simultaneously for one minute. Each sample of 10 beetles was replicated 5 times.

Insecticide solutions were formulated in concentrations of 20, 40, and 80 mg. DDT/ml. solvent so that 1 ml. of solution applied to each fibreboard block would give 320, 640, and 1,280 mg. DDT/ft.^{2}, respectively.

Duplicate deposits from DDT-acetone and DDT-xylene solutions were prepared on both dry and moist fibreboard blocks. Blocks were dried by placing them in an oven at 50 degrees C. for 24 hours. The loss in weight averaged 3.9 percent. Blocks were moistened by placing them in a desiccator over a free water surface for eight days (figure 15). The results of this exposure provided an average weight gain of 3.3 percent. These two extremes of moisture content (3.9 percent loss and 3.3 percent gain; a range of 7.2 percent) were far in excess of the hourly fluctuations in moisture content of both fibreboard and ponderosa pine bark exposed to laboratory conditions under which the tests were conducted. Whereas artificial control of moisture content produced a range of 7.2 percent between maximum and minimum weights, hourly weighings of fibreboard between 9 a.m. and 11 p.m. showed a range of only 0.24 percent between the maximum and minimum weights. Ponderosa pine bark showed a range of 0.61 percent. The relatively large changes in weight induced artificially, therefore, were believed to be of great enough magnitude to excel even those changes in weight of fibreboard blocks held outdoors that would be caused by daily changes in relative humidity (excluding effects of rainfall) through the active months of beetle emergence.

Those blocks dried in an oven were allowed to return to room temperature before they were treated to avoid introducing the possible

Figure 15.--Fibreboard blocks held in a desiccator over a free water surface to raise the moisture content.

variable of substrate temperature. Cooling time plus treatment with the insecticide required about 20 minutes and in this period of time the fibreboard blocks absorbed about 100 mg. of water vapor from the air. This represented about 11 percent of the weight of water removed in the drying process.

All deposits were bioassayed two months after application of the insecticide.

RESULTS

Figure 16 (table 10, appended) presents the findings for both the acetone and xylene deposits. The darkened bars are results on dry substrate and the white bars are results on moist substrate. Mean and standard error are indicated by hatching. Natural mortality was 0 percent.

No significant differences in mortality were obtained with either solvent at the three levels of dose tested. Standard errors overlapped in all but the tests with DDT-acetone deposits at the 640 mg. dose level. A t-test showed a non-significant difference: $t=1.52$ at 8 degrees of freedom giving a probability of a larger value for t of 0.20 to 0.10. This was below the probability level of 0.05 selected as the level of significance.

The DDT-acetone deposits were most toxic at the dose level of 320 mg. decreasing in toxicity with increasing dose. The DDT-xylene deposits were most toxic at the 640 mg. dose level indicating that deposits of DDT made from heavier solvents may show optimum toxicity at higher levels of dose. Also, DDT-xylene deposits were equal to or more toxic than the DDT-acetone deposits.

The states of deposits appeared identical whether the substrate was dry or moist. Differences in the deposits were observed only between the three levels of dose with both the DDT-acetone and DDT-xylene deposits. The DDT-acetone deposits were typically composed of a light amorphous incrustation and acicular crystals of two size classes. Border crystals surrounding the areas of incrustation ranged from 50 to 600μ long. Crystals within the areas containing an incrustation were smaller, ranging from 20 to 100μ long. Neither crystal structure, density, nor coverage differed between dry and moist substrates. A visual estimate of coverage to the nearest five percent for deposits on dry and moist substrates was as follows:

Dose	Approximate coverage (percent)	
(mg.DDT/ft.^{2})	Dry substrate	Moist substrate
320	20	20
640	85	90
1,280	95	> 95

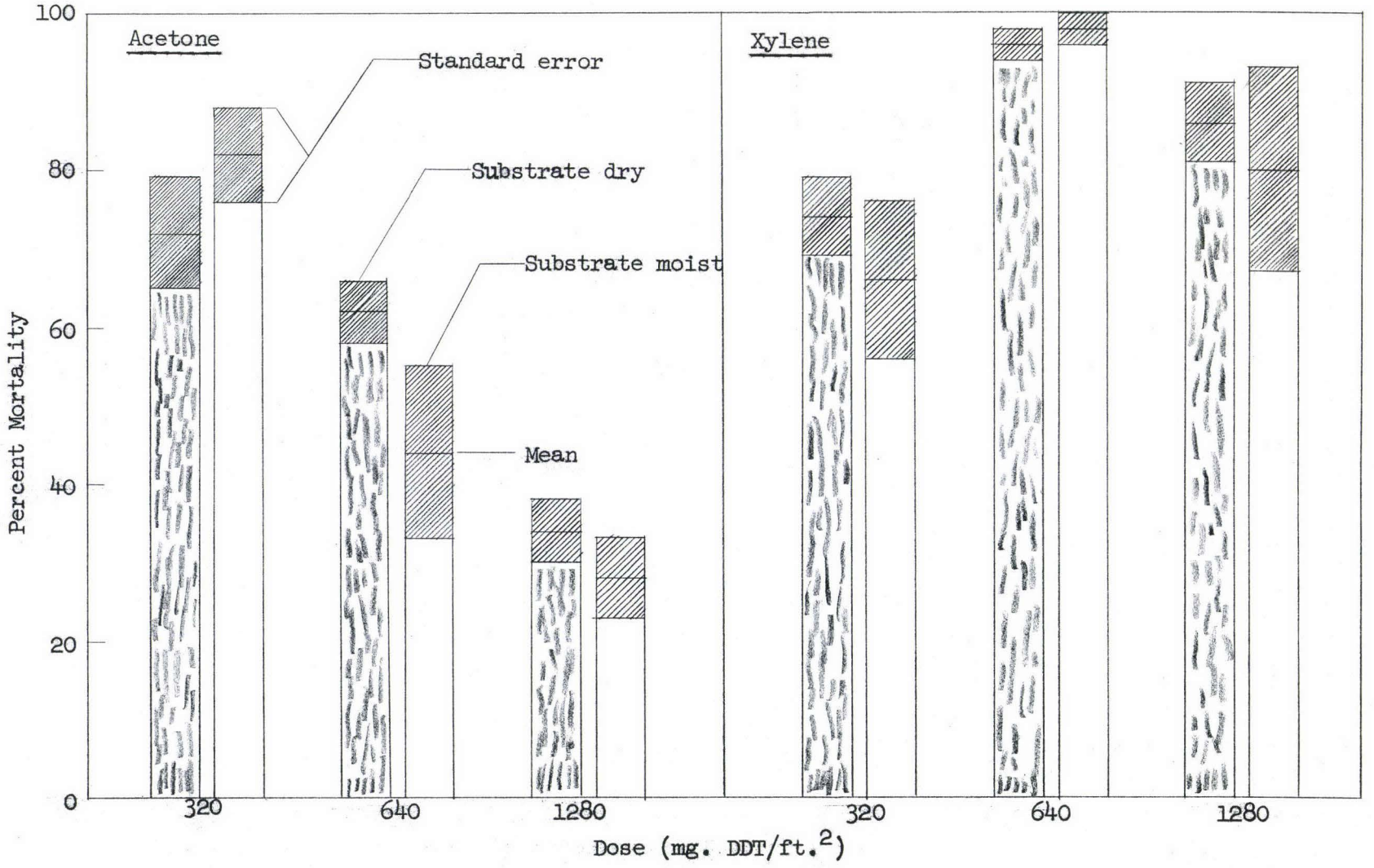


Figure 16.--Mortality of Ips confusus adults exposed for one minute to DDT-acetone and DDT-xylene deposits on dry and moist fibreboard blocks.

The DDT-xylene deposits were composed of a much lighter incrustation than DDT-acetone deposits. Crystals were similar, being acicular and ranging from 20 to 600μ long but were not clearly separated in two size classes. Crystals within areas having an incrustation were not clearly different in length from crystals occurring on areas of the substrate devoid of the light incrustation. There was a tendency for the acicular crystals within incrustation areas to be represented by members less than 100μ long. The shorter crystals, therefore, appeared to be more abundant within areas of incrustation whereas all crystals in areas devoid of incrustation were predominantly 100 +μ in length.

Crystal structure, density, and coverage were the same in DDT-xylene deposits on dry and on moist substrates. Coverage at each level of dose, for both dry and moist substrates was estimated to be as follows:

Dose (mg. DDT/ft.^{2})	Approximate coverage (percent)	
	Dry substrate	Moist substrate
320	< 5	< 5
640	10	15
1,280	85	90

DISCUSSION

No significant differences could be found in the states of deposits or in toxicity of deposits of DDT in acetone and DDT in xylene, at doses of 320, 640, and 1,280 mg. DDT/ft.^{2}, when applied to fibreboard of low or high moisture content. These results are surprising in view of the wide variability in deposits from one application to the next, which suggests that only slight changes in the substrate, in the environment, or in the method of application may have strong effects on the development of the deposits.

FUMIGATING ACTION OF INSECTICIDE DEPOSITS

Exposure to deposits is made by confining test beetles to the treated surface with a watch glass. The substrate, fibreboard, is relatively smooth except for microscopic irregularities caused by the complex intermingling of fibres at the surface. Insecticide vapors are heavier than air and should tend to settle in the enclosure created by the watch glass. A certain proportion of the vapors may escape under the rim of the watch glass where it contacts the substrate but, nevertheless, a concentration of vapors probably builds up beneath the watch glass. The concentration of these vapors depends, in part, on the length of time the watch glass is held on the substrate. Since expressions of the toxicity of deposits are obtained by exposing beetles to them for varying periods of time under a watch glass, it is important to know whether mortalities from the longer exposure periods are augmented by a fumigating effect of the insecticides. Comparisons of residual toxicities of insecticides would be invalidated

by a fumigating effect from one and not the other. And the occurrence of vapors in toxic concentrations beneath the watch glass would encourage an overestimation of the toxicity of a given deposit.

MATERIALS AND METHODS

Investigations of potential fumigating action were begun with DDT-acetone deposits applied at the rate of 320 mg. DDT/ft.^{2} Tests were run with Ips confusus adults confined to the deposits with the standard unaltered watch glass, providing a standard regression of mortality over exposure time. A parallel test was run using a watch glass from which the center portion was removed with a glass cutter; the portion removed was about one-half the diameter of the watch glass. As an additional precaution, a slight current of air from an electric fan was directed toward the altered watch glass while beetles were being exposed, to aid in preventing an accumulation of insecticide vapors. Exposure with an intact watch glass and one with the center removed, therefore, provided the test for potential fumigating action. It was assumed that the altered watch glass plus the air current prevented the accumulation of a toxic concentration of DDT vapors.

Exposure times ranged from 0.25 to 20 minutes. A sample of 10 beetles was used at each exposure, replicated from 2 to 4 times. The mortality curves were rectified by the probit method as treated by Finney (4). All deposits were 40 days old when used in these tests.

RESULTS

Figure 17, (table 11, appended) shows the regression curves for the tests using the intact watch glass, which would show the added effects of fumigation if any, and using the altered watch glass to avoid fumigation. The slopes were very low and non-parallel, with values of 0.9883 and 0.5470, respectively. Toxicity comparisons at the 90 percent level of kill showed that there was no difference (95 percent confidence) whether an intact or altered watch glass with air current was used for testing. The exposure time required to kill 90 percent of the beetles along with 95 percent fiducial limits for the two exposure methods were as follows.

Exposure method	Exposure time for 90 percent kill (minutes)	95 percent fiducial limits (minutes)
Intact watch glass	6.48	3.65 - 11.49
Cut-out watch glass	16.22	3.76 - 69.98

DISCUSSION

Most exposures in the bioassay of deposits, are limited to 10 minutes or less, thus it is not likely that fumigation plays a significant

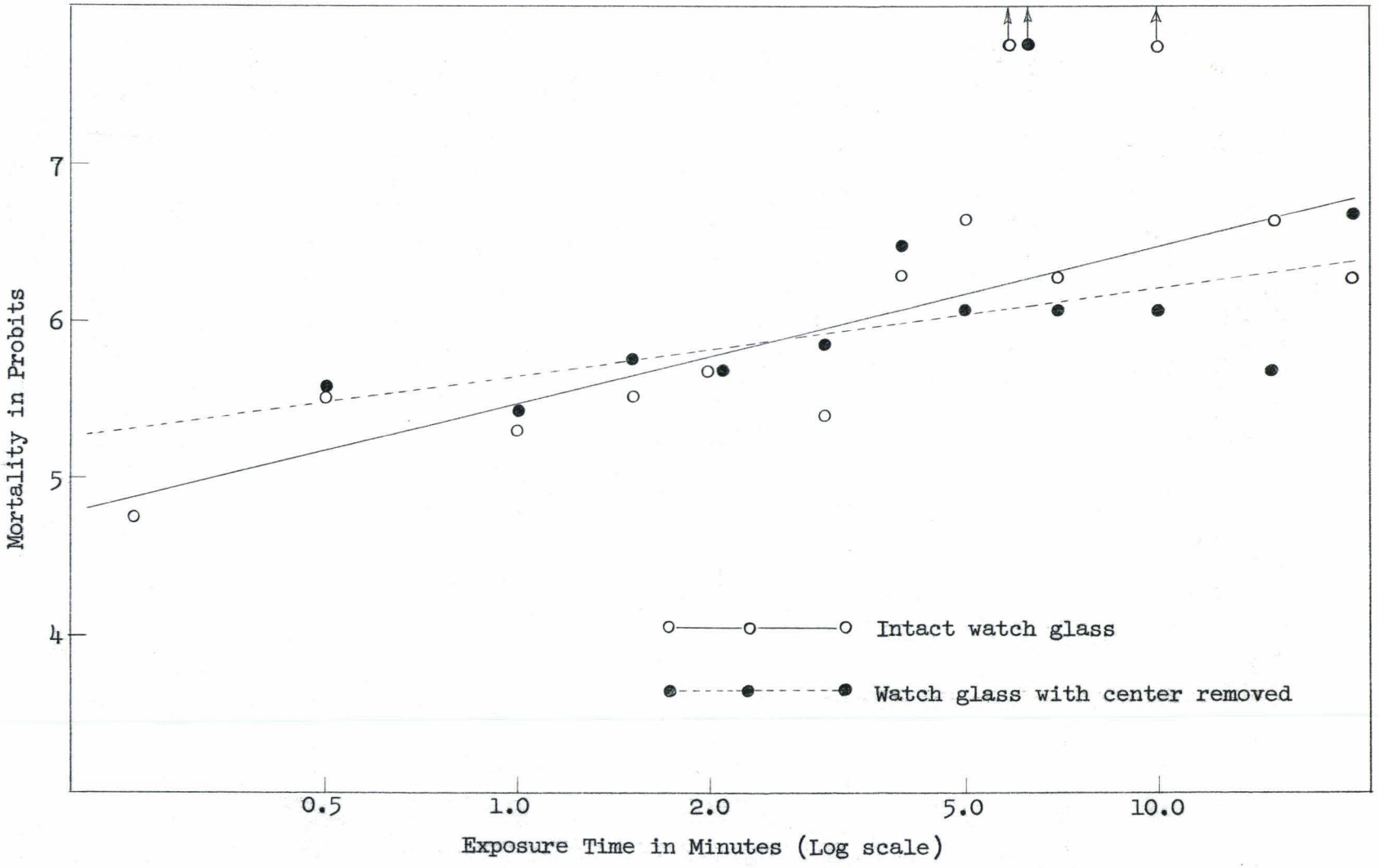


Figure 17.--Mortality of Ips confusus adults exposed to DDT-acetone deposits under an intact watch glass and one with its center cut out to test the fumigating action of DDT deposits.

part in the mortality of beetles exposed to DDT deposits. DDT has a notably low vapor pressure, whereas other residual-type insecticides like endrin, dieldrin, and lindane have much higher vapor pressures. The fumigating action of some of the more volatile insecticides, especially lindane, may be great enough to affect mortality at relatively short exposure periods. The fumigating action of these insecticides should be investigated.

Future tests of fumigating action should be simplified to exclude toxicity contributed by contact with the deposit. A more precise pinpointing of the exposure time needed to produce the first signs of significant fumigation can be made by subjecting beetles to the vapors alone.

DESIGN OF A SPRAY CHAMBER

The application of insecticides to sections of fibreboard in laboratory tests on states of deposits has been done exclusively with a pipette. Although a convenient and accurate means of applying the insecticides, the pipette has three major limitations: (1) quantities of less than one-half milliliter of solution cannot be applied uniformly to the standard 3- by 3-inch substrate; (2) an even distribution of the solution over the surface of the substrate depends upon careful systematic maneuvering of the loaded pipette above the substrate, which is subject to error in judgment; and (3) application by pipette is time-consuming.

A spray chamber designed by Eaton and Secrest (3) was investigated for suitability in studies of states of deposits as a replacement for, or supplement to, application by pipette. With this apparatus, the spray is introduced horizontally through one end of a rectangular chamber. In this way deposits of different drop size can be had since large drops are driven further than small ones. Two square openings in the floor of the chamber allow the spray to fall on objects placed beneath them to be treated. The openings are located at different distances from the spray nozzle, permitting deposits to be made of different drop size.

The spray is applied with a nose and throat atomizer. The amount of spray entering the chamber is controlled by the actuation of a shutter between the nozzle and chamber opening. A special timing apparatus controls the opening and closing of the shutter.

A spray chamber constructed at the Lake States Forest Experiment Station, Division of Forest Insect Research, St. Paul, Minnesota, modified slightly from the original chamber by Eaton and Secrest, was borrowed to study its suitability in studies on states of deposits. A major modification in this chamber was the addition of an extra opening (making a total of three) in the floor of the chamber proper. The three openings led to another chamber beneath (hereafter called receiving chamber) that was completely closed, and access to it for placement of objects to be sprayed was provided for by a wide door hinged at its upper edge.

Experimentation with the chamber served to familiarize us with its operation and to point up changes in its design or operation needed to accommodate the specialized requirements of studies of deposits.

In our studies, spray application was made with hydraulic nozzles, instead of the siphon-type, to eliminate the need for a constant level reservoir; to permit application of larger amounts of insecticide; and to eliminate the production and escape of clouds of finely atomized spray which are a hazard to the operator. Pressure was supplied by a $\frac{1}{4}$-horsepower air pressure and vacuum pump which provided a smooth and pulseless air delivery. A heavy-wall, filtering flask was used as the insecticide reservoir. The air supply was attached to a tubulation on the neck of the flask. The flask was stoppered with a rubber cork in the center of which a piece of glass tubing was inserted to furnish a connection for a polyethylene line from the nozzle. The shutter opening and closure was controlled by a special timing device supplied by the Lake States Forest Experiment Station, Division of Forest Insect Research. The nozzle was held in place with a modified C-clamp.

Experimentation with the spray chamber was conducted with kerosene solutions of Dupont oil soluble red dye applied to 6- by 6-inch aluminum plates. The amount applied was determined with the Duboscq-type, direct-reading colorimeter. Studies of the spray pattern on white sheets of paper showed that the most uniform deposits could be obtained with 4 to 8 pounds of pressure using a Monarch nozzle producing a flat spray.

The standard error of the amount of kerosene-oil red dye solution applied during the initial tests with the spray chamber varied from ± 3 to ± 22 percent. When the causes of this variation were eliminated the standard error could be kept between ± 3 to ± 6 percent. These latter results were as follows (Monarch nozzle #20, flat spray):

Pressure (lb./sq. in.)	Time of shutter opening (sec.)	Dose/ft.^{2} (ml.)	Standard error
4	1	0.340	± 0.016 (± 5%)
5	1	0.524	± 0.012 (± 3%)
5	1	0.496	± 0.024 (± 5%)
5	1	0.548	± 0.020 (± 4%)
5	4	1.848	± 0.052 (± 3%)
5	4	1.944	± 0.080 (± 4%)
6	1	0.588	± 0.036 (± 6%)
7	1	0.620	± 0.028 (± 4%)
7	4	2.468	± 0.084 (± 3%)
8	1	0.604	± 0.032 (± 5%)

The amount deposited can be varied by changing the pressure; time of shutter opening; and the size of the nozzle orifice. With the right combination of these changes a very wide series of delivery rates is possible.

The major sources of error that proved to be responsible for the wide variability in the initial tests were:

1. External air movement - it is essential that the spray chamber be shielded from air currents to avoid turbulence inside the spray chamber that disrupts the spray pattern.

2. Opening and closing of the receiving chamber door - each time the receiving chamber door is opened or closed to insert or remove a test surface, turbulence is created within the chamber proper and again the spray pattern is disrupted. This can be prevented by redesigning the door so that it slides rather than hinges.

3. Contamination by runoff - spray that falls in the vicinity of the substrate but not on it eventually accumulates to the point where some adheres to the edges of the substrate. Contamination can be prevented by placing the substrate on an absorbent surface or raising it slightly from the floor of the receiving chamber.

Work with the spray chamber showed that it was basically suitable for use in studies on states of deposits. Several modifications seemed desirable, however, to reduce error in delivery rate and to make the chamber flexible enough to accommodate many of the different types of pilot tests of insecticides that may be necessary from time to time. With these needs in mind, a spray chamber was designed (not yet constructed) with the following modifications:

1. The entire spray chamber was designed so that it can be taken apart easily and any of the separate parts can be redesigned to fit a unique testing situation if the need arises. For instance, the base of the spray chamber proper can be replaced by one with more or fewer, larger or smaller, openings, or the receiving chamber can be replaced with one of different dimensions.

2. Provision was made for collection of runoff from spray impinging on the top and sides of the spray chamber proper. This will prevent the spray from soaking into the wooden receiving chamber, creating unsightliness and producing hazards of contact toxicity to the operator.

3. The rear of the chamber was provided with a large, tightly fitting door to allow periodic cleaning of the chamber's interior.

4. A sliding door was provided that can expose as small an opening as desired at any point along the front of the receiving chamber. This will reduce turbulence in the spray chamber caused when test surfaces are inserted and removed.

5. The overall dimensions of the spray chamber were increased slightly to permit the simultaneous treatment of a greater number of items and also the treatment of larger items.

6. A new nozzle holder was designed to hold the nozzle securely and to permit the exact replacement of a nozzle or the substitution of a different nozzle when needed.

7. An electronic timing device for actuating the shutter was obtained that will give very precise control (within a 10 percent drop in line voltage) of shutter openings of 1 to 10 seconds in increments of 1 second. The apparatus can be altered readily to control shutter openings of 0.1 to 10.0 seconds in increments of 0.1 second, if the need arises.

FIELD TESTS

Small-size, "field" tests of residual-type insecticides for the control of bark beetles infesting ponderosa pine were begun. The tests were designed so that laboratory findings from studies of states of deposits could be evaluated on a practical basis. The tests also furnish direction for further laboratory studies insofar as they record the important characteristics of deposit behavior on bark under field conditions.

MATERIALS AND METHODS

Ponderosa pine logs infested with Dendroctonus brevicomis Lec. and Ips confusus (Lec.) were collected from the field when the insects were in late stages of development and about ready to emerge. Care was taken to find logs that were uniformly infested so that the number of insects present under any unit area of bark was about equal.

The infested log was sectioned transversely into 16-inch bolts which were separated into groups of 5 or 6 for receiving a given treatment. Because of taper in the log, the surface area and also the potential insect population of each bolt decreased with distance from the butt. The bolts were thus distributed so the full length of the log was represented, and the total surface area was about equal in each group of bolts. The use of uniformly infested logs and the grouping of bolts as described were the two precautions taken to get equal sample sizes for the tests of various insecticide treatments.

These first field tests were devoted to testing the laboratory finding that pp' DDT deposits are most toxic at some optimum dose, falling off above and below this value. Laboratory tests of 160, 320, 640, and 1,280 mg. DDT/ft.^{2} in acetone carrier showed the 320 mg. dose to be most potent on fibreboard (7). Lindane behaved similarly.

The field tests were conducted with pp' DDT using xylene as a carrier. Xylene was chosen as the solvent because of the convenience of handling it and because it dissolves large amounts of DDT without the need for auxiliary solvents. Auxiliary solvents were avoided intentionally because their effects on states of deposits are not fully understood and their inclusion in these tests would complicate the interpretation of results.

Doses of 320, 640, and 1,280 mg. DDT/ft.^{2} were selected and each dose was replicated 5 times (1 bolt = 1 replica) in tests with D. brevicomis and 6 times in tests with I. confusus. Equal sample sizes were maintained as untreated controls.

The spray was applied with a small, hand-operated sprayer held at a distance of one foot from the bolt and raised and lowered as the spray was discharged in order to cover the full 16-inch length as uniformly as could be visually estimated.

The spray gun was filled with 100 ml. of the spray solution, pressurized, and completely emptied on a given bolt. Different dose levels were applied by varying the amount of insecticide in the 100 ml. volume: 2,000 mg. DDT/100 ml. for the 320 mg. dose; 4,000 mg. DDT/100 ml. for the 640 mg. dose; and 8,000 mg./100 ml. for the 1,280 mg. dose.

Previous experimentation with the spray gun showed that about 60 percent of the spray actually impinges on the bark surface under the conditions of the procedure followed. About 40 percent is deflected as a fine mist. This was determined by spraying known volumes of insecticide on bark and making pre- and post-spray weighings to estimate the percent that was deposited. Since the average bolt had 3.7 ft.^{2} of bark surface, 60 percent of the 100 ml. of solution gave the approximate doses sought.

Application of the insecticide offered the greatest potential source of error because of the extreme difficulty of getting a uniform and equal amount of spray on replicas having a cylindrical shape. Application was made by suspending the bolt about breast height from an overhead support by means of a heavy twine attached to the bolt through a centrally located staple. In this way, the bolt could be revolved freely and application of the spray could be made to all sides of the bolt without circling it.

The sprayed bolts that received a given treatment were held in separate 6- by 6-foot compartments of a 16-mesh, wire-screen insectary located outdoors (figure 18). Control bolts were also held in a separate compartment.

The effectiveness of the treatments was determined by collecting the beetles separately in size #000 gelatin capsules as they emerged and making mortality counts 72 hours later. Clerid and ostomid adults that

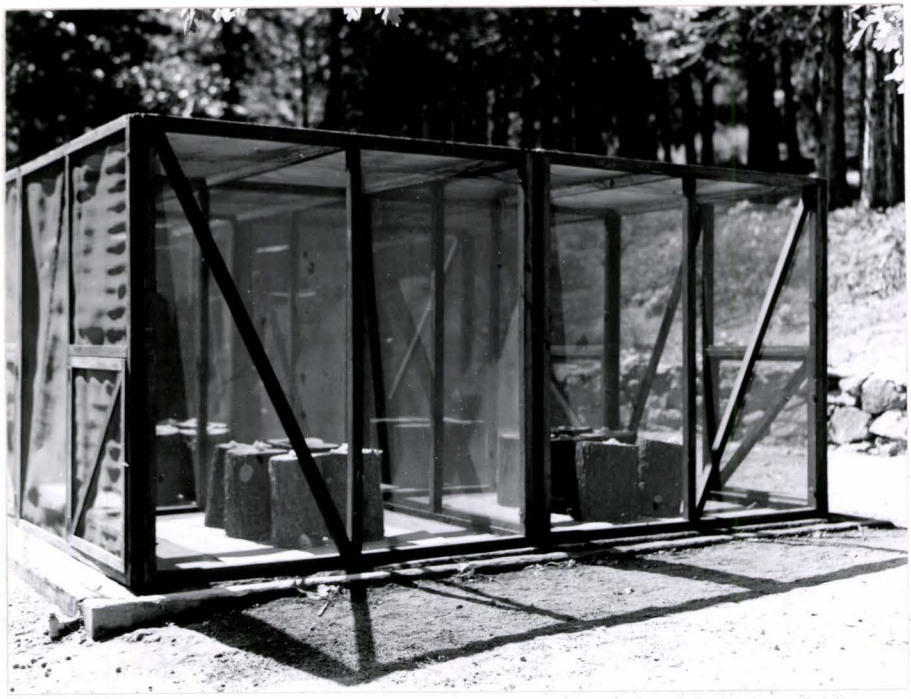


Figure 18.--Test bolts arranged in 6- by 6-foot, wire-screen, cage compartments to entrap emerging adults.

emerged were also collected and held for mortality counts. Collections were made twice daily, at 12 noon and 6 p.m.

A thorough search was necessary at each collection to assure that all emerged beetles were recovered, otherwise those that were missed would carry over to the next collection. Being older to begin with, they would add to the variability of the 72 hour mortality counts. Many of the beetles were visibly impaired by the insecticide shortly after they emerged and would seek tiny crevices and pits in the floor and walls of the cage, or would seek refuge under the bolts, often dying in place. All beetles were collected whether dead or alive and no attempt was made to record the early deaths, since the 72 hour mortality count has been chosen as the sole basis of estimating toxicity in all tests conducted.

RESULTS WITH D. BREVICOMIS

The mortality curves shown in figure 19 (table 12, appended) represent mortalities on successive days following treatment with the DDT-xylene solutions. The horizontal scale shows that emergence took place over a period of about two weeks. At the end of this time, emergence was reduced to about 10 adults per 5-bolt sample. Collections were discontinued at this point because such small sample sizes do not provide a reliable basis for estimating mortality.

During the 2-week emergence period, mortality from all three treatments rose from a low point of about 10 to 50 percent on the first day following treatment to a high of about 75 to 100 percent on the last day emergence was recorded.

The lightest dose of 320 mg. was always less potent than the 640 mg. dose and less potent than the 1,280 mg. dose throughout most of the emergence period except for the 13th and 14th days. Mortalities from the two highest doses (640 and 1,280 mg.) were similar during the first week of emergence and then diverged during the second week, with the 640 mg. dose showing the greater potency.

The curves of figure 19 therefore indicate that the intermediate dose of 640 mg. was the most effective when the deposits reached a more advanced age. The relative efficiency of the three doses is altered somewhat when all emergence data are pooled (table 13). The 320 mg. dose was decidedly inferior and the two higher doses produced identical mortalities. A doubling of the dose from 640 to 1,280 mg. completely failed to improve the total mortality of emerging adults.

The total emergence from bolts receiving each dose point to a need for caution in interpreting the mortality results.

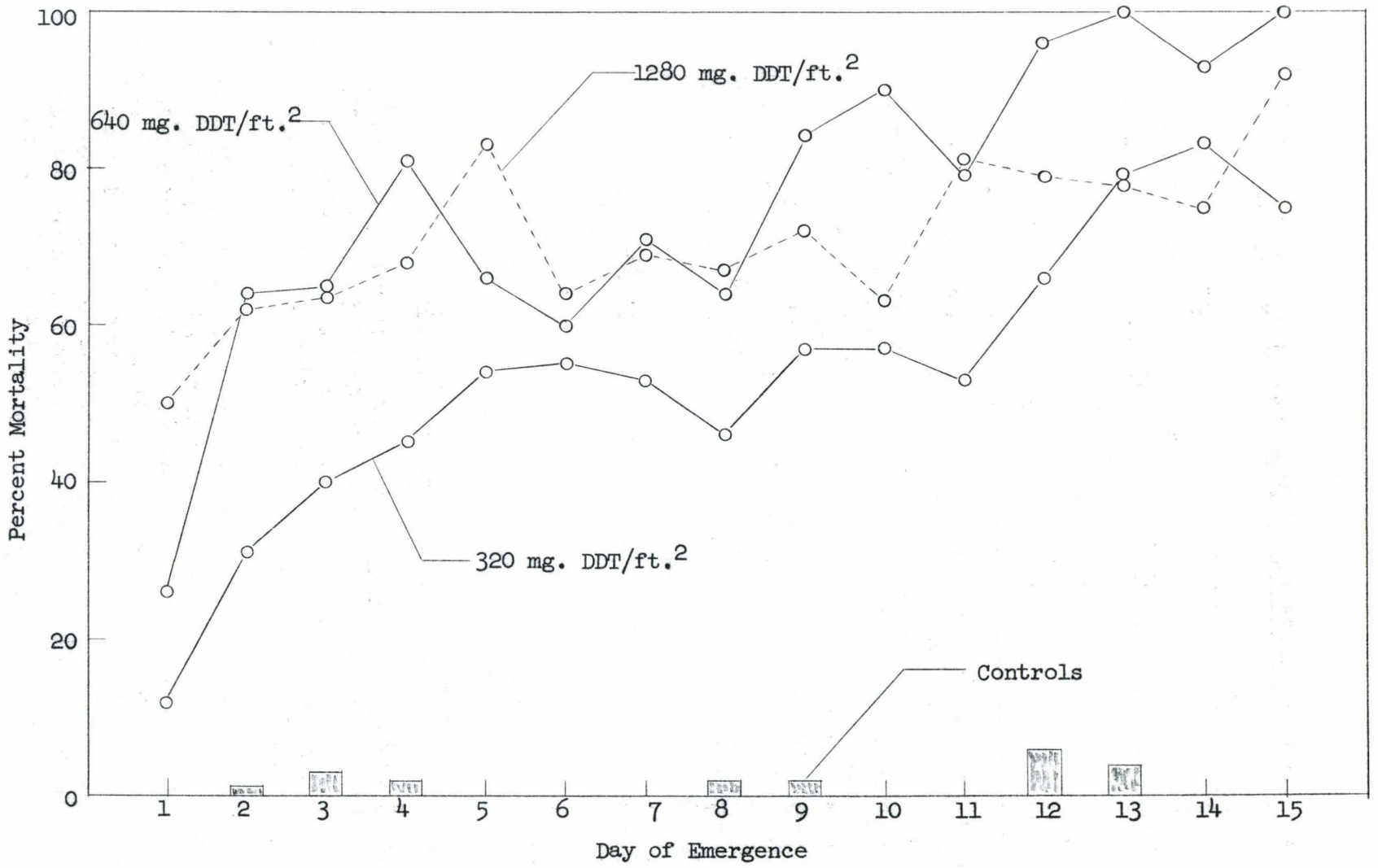


Figure 19.--Mortality of Dendroctonus brevicomis adults emerging from ponderosa pine bolts treated with DDT-xylene solutions.

Table 13.--Pooled mortality of Dendroctonus brevicomis adults

Dose (mg. DDT/ft.^{2})	No. of insects	No. dead (72 hr.)	Mortality (percent)
0	738	9	1
320	677	332	49
640	634	450	71
1,280	485	339	70

Table 13 shows that total emergence declined progressively, from zero dose to the maximum dose used. It is not known whether this differential in emergence is an accurate representation of original beetle density in each group of test bolts, or whether, as dose was increased, more and more beetles were killed in place before they could emerge. However, even if we assume that increasing numbers of beetles were being killed in place as dose was raised, the relative mortalities are still similar and indicate little or no difference between the 640 and 1,280 mg. doses; this is pointed up when control emergence is taken as a base and the emergence deficits are added to the tally of deaths:

Dose (mg. DDT/ft.^{2})	No. insects	No. dead	Mortality (percent)
0	738	9	1
320	738	393	53
640	738	554	75
1,280	738	592	80

Effect of Beetle Size on Mortality

The size of D. brevicomis adults was determined by measurements of the length of the elytra. These ranged from 1.5 to 3.2 mm. There was also a progressive drop in the average size of the beetles in the day-to-day emergence from both the treated bolts and the controls (table 14, appended).

A very strong correlation between adult size and mortality was shown by arranging the insects in size classes and tallying their respective mortalities (table 15, appended). This correlation held for all three treatments (320, 640, and 1,280 mg. DDT/ft.^{2}), although it was more evident in the 320 mg. treatment because mortality was closest to 50 percent. A meaningful correlation for the control insects could not be shown because average mortality was only 1 percent (table 13). The effect of increasing the dose of DDT was to kill more of the larger insects.

The correlation between beetle size and mortality can best be shown by the data from the 320 mg. dose, depicted in figure 20. None of the beetles of the 3.2 mm. class were killed. As size decreased, kill rose more or less in a straight line, reaching 100 percent as size decreased to 1.6 and 1.5 mm.

It is important to consider the effect of size on mortality when interpreting the mortality curves of figure 19 since the average size of the beetles emerging from day to day was decreasing, and with decreasing size, there was, as shown, a concurrent increase in mortality. Again, considering the data for the 320 mg. treatment, the average beetle size of day-to-day emergence ranged from about 2.00 to 2.60 mm. (table 14 appended). If a straight line is drawn through the mortality data of size classes 2.0 to 2.6 mm. in figure 20, it is found that for every 0.1 mm. change in size there is a 7.0 percent change in mortality. This information was used to reconstruct a mortality curve based on the average size of the total emergence, which was 2.42 mm. The mortality of the beetles of each day's emergence, therefore, was estimated on the basis of what would be expected if the average size was 2.42 mm. regardless of emergence date (table 16, appended). The following formula was used:

$$M + (S-2.42) \times 0.7 \times 100$$

M = the actual mortality of a given day's emergence.

S = the average size of a given day's emergence.

2.42 = the average size of all the emerged beetles from the 320 mg. treatment.

0.7 = the percent change in mortality for every 0.01 mm. change in beetle size.

100 = converts the result to percentage.

The adjusted mortality curve is shown in figure 21 along with the plot of actual mortality. With the effect of varying size eliminated, the curve can be seen to become somewhat flatter. Mortality increased sharply for the first 4 or 5 days but increased little or not at all thereafter. The initial increase in mortality might be explained by an improvement in the state of the deposits on the bark surface. It was shown last year (7) that DDT on fibreboard reached close to its greatest toxicity after the first few days of aging, and improved little more in the following 1 or 2 months.

States of Deposits

An attempt was made to record the states of deposits as they developed on the treated bolts in the event that differences in mortality

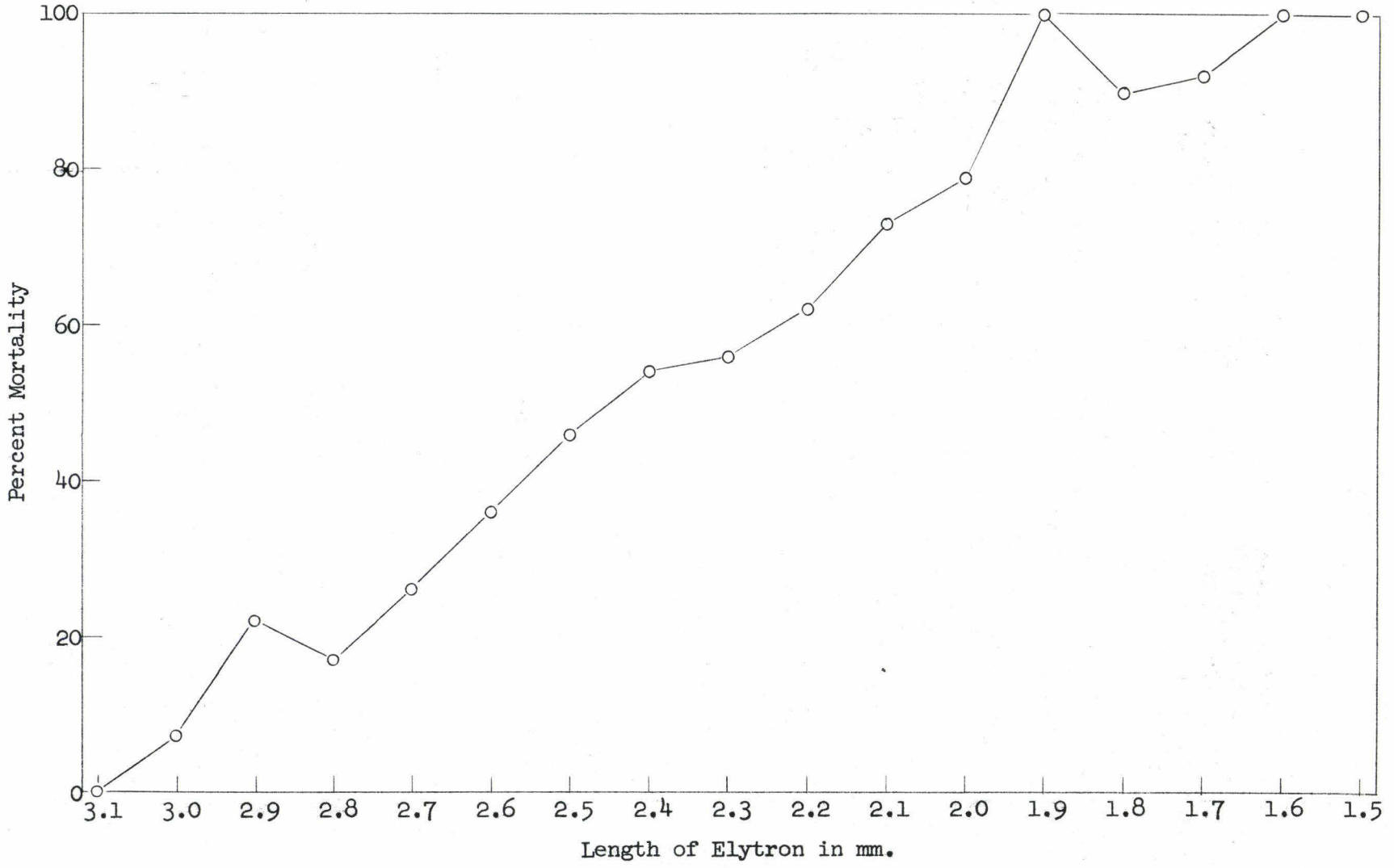


Figure 20.--The influence of body size on the mortality response of Dendroctonus brevicomis adults emerging from ponderosa pine bolts sprayed with 320 mg. DDT/ft.^{2}.

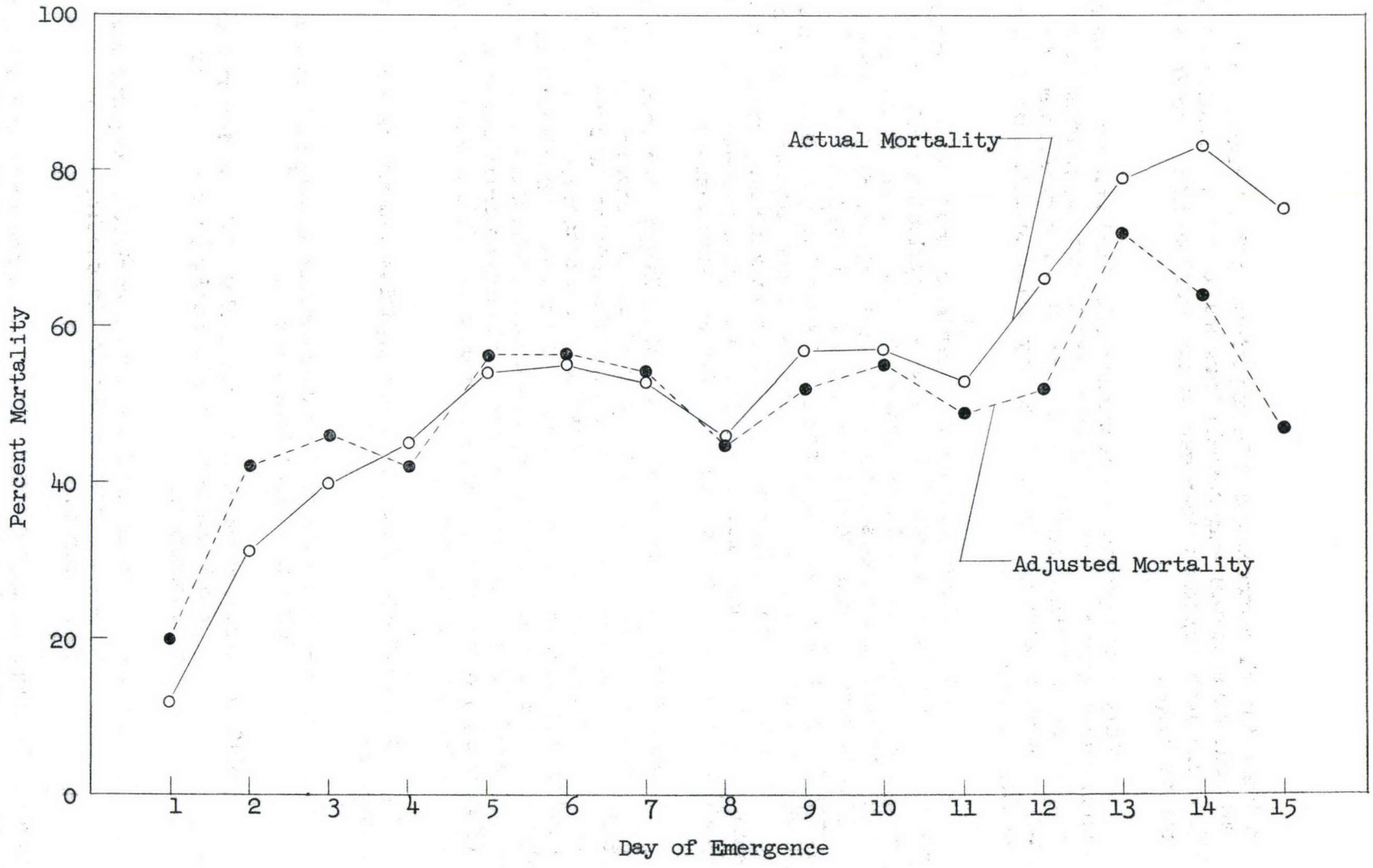


Figure 21.--Actual and adjusted mortality of Dendroctonus brevicomis adults emerging from bolts treated with 320 mg. DDT/ft.^{2}.

between the three doses could be explained by differences in the deposits. This was done by removing a small bark scale from each bolt on the 2nd, 7th, and 14th day after they were treated and examining them under a binocular scope.

Only a few general conclusions could be drawn from these observations because of the extreme difficulty of getting quantitative estimates of such deposit characteristics as crystal coverage and density. The size and shape of crystals are the only characteristics subject to easy quantification.

The states of deposits were preeminently variable even within small areas of the bark surface. The more typical deposits are shown in figures 22 and 23. The deposits were always composed of needle-like or acicular crystals which differed in size and shape. They ranged between 10 and 100μ in length and < 5 to 20μ in width. Most crystals were 20 to 50μ long and 5 to 10μ wide. On a given area of bark, the crystals were either uniformly of one size and shape, or, more often, a mixture. Coverage and density varied sporadically without a predictable pattern. Also there were no apparent differences in the deposits from the 2nd, 7th and 14th day observations.

The deposits of the 320, 640, and 1,280 mg. treatments differed to some extent. The 640 mg. dose showed the best coverage and the best density. All three treatments had crystals reaching 100μ in length but in decreasing abundance in the following order: 320 > 640 > 1,280. Most crystals were 20 to 50μ regardless of dose. Broad crystals about 20μ wide occurred in decreasing abundance in the following order: 640 > 320 > 1,280. Very dense, localized aggregations of crystals (figure 22B) occurred abundantly at a dose of 1,280 mg. and not at all at the 320 and 640 mg. dose levels.

The three major differences in deposits between dose levels was as follows:

320 mg. - contained more crystals reaching 100μ in length than the other two deposits.

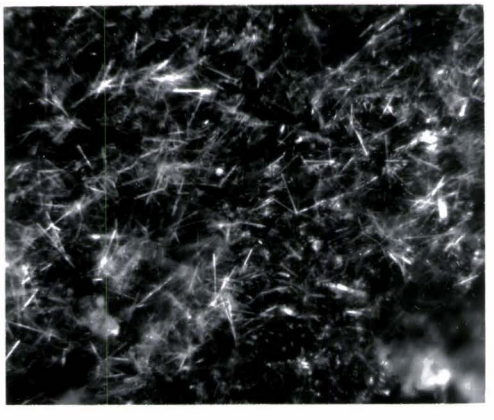
640 mg. - showed better coverage and density, and contained more broad needles (20μ wide) than the other two deposits.

1,280 mg. - unique in having dense, localized aggregations of needle crystals abundantly scattered over the bark surface.

The needle aggregates typical of the 1,280 mg. dose constituted a large part of the total physical mass of the deposit. Availability of the deposit to the insect is probably greatly reduced when the crystals are clumped in this way, which may account for the lack of improvement in

A

B



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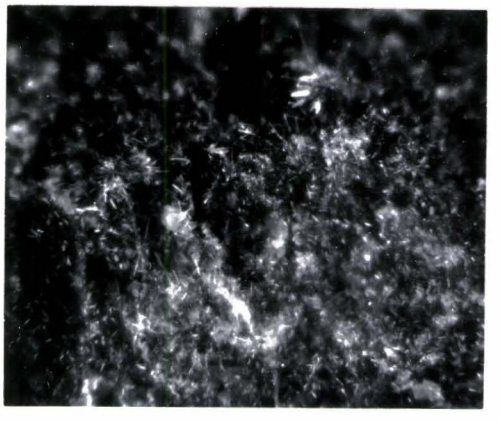
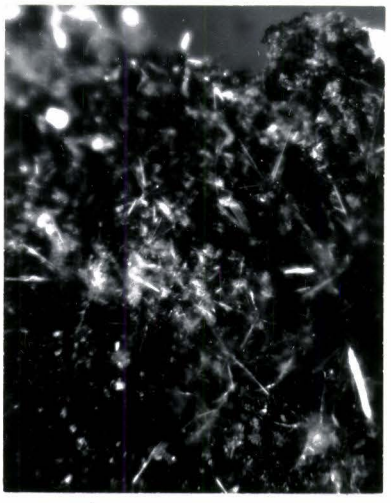
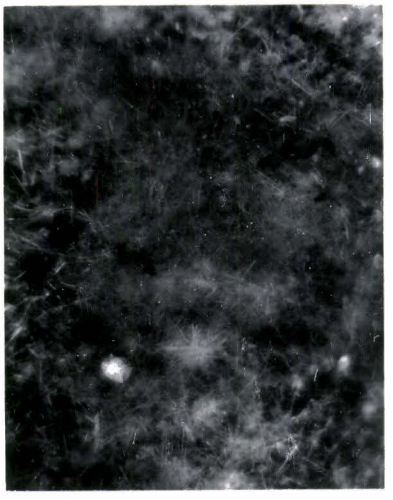


D

Figure 22.--Characteristic deposits obtained on ponderosa pine bark with DDT-xylene solutions: A - broad needle crystals (20μ wide) common with 640 mg. dose; B - tight aggregates of acicular crystals common with 1,280 mg. dose; C - long acicular crystals reaching 100μ ; D - very short needles 20μ and less. All photographs 54X.



A



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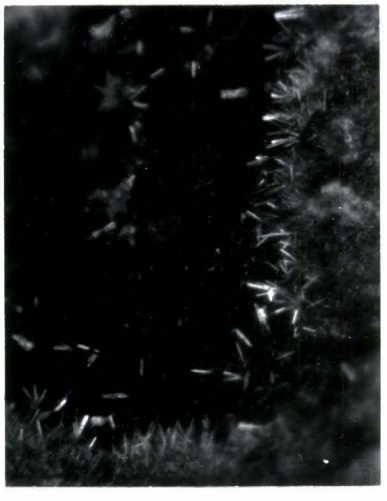

C

Figure 23.--Characteristic deposits obtained on ponderosa pine bark with DDT-xylene solutions: A - loose mixture of various shapes and sizes of acicular crystals most frequently found; B - very fine and extremely dense cottony mass of acicular crystals; C - border crystals that sometimes occur at the periphery of a crystallized area. All photographs 54X.

the deposit when doubled from 640 to 1,280 mg. DDT/ft.^{2} The greater uniformity of coverage and density and the abundance of broad needles may also contribute to the 640 mg. deposit being as effective as the 1,280 mg. deposit.

Parallel Test on Fibreboard

Fibreboard blocks (3- by 3-inches square) were treated with three dose levels (320, 640, and 1,280 mg.) of DDT-xylene solutions, at the same time the bolts were treated, to check for similarities in deposit behavior on the two different substrates. The fibreboard blocks were stored vertically in a sunny area next to the cages containing the treated bolts. In this way, the fibreboard blocks and the bolts were exposed to similar environmental conditions.

The blocks were bioassayed with D. brevicomis adults (using the standard techniques) on the 10th, 12th, and 14th day after treatment. Exposure time was one minute.

Mortality was so low that the data for the three different exposure dates were grouped to produce table 17.

Table 17.--Mortality of D. brevicomis adults exposed to DDT-xylene solutions on fibreboard for one minute

Dose (mg. DDT/ft.^{2})	No insects	No. dead (72 hr.)	Mortality (percent)
0	100	1	1
320	230	6	3
640	230	3	1
1,280	280	10	4

Because of the very low kill, it is pointless to interpret mortality differences between dose levels. Significantly, however, D. brevicomis adults have been shown to remain a minimum of 60 seconds on the bark surface between emerging and taking flight (8), and the fibreboard blocks were bioassayed with adults, using a 60-second exposure period. The point is that the 60-second exposure period on fibreboard produced a very low kill (1 to 4 percent), whereas average mortality of adults emerging from the test bolts ranged from about 50 to 70 percent (table 13). The greater mortality of the emerging beetles was due to a more efficient deposit; to extra pick-up through ingestion as the beetle emerges through the shallow outer bark layers that undoubtedly contain considerable quantities of insecticide; to greater pick-up resulting from an average exposure of greater than 60 seconds between emergence and flight; or to all or a combination of the above three factors.

It is not possible to say which factor or factors were responsible for the greater mortality of the emerging beetles. However, some of the differences in mortality were very likely caused by differences in the deposits between the fibreboard and the test bolts. Crystallization was far less abundant on the fibreboard, occupying only between 1 and 10 percent of the surface. The crystals were extremely fine (< 5μ wide) and mostly 50 to 150μ long (figure 24); however, lesser toxicity was probably due mostly to poor coverage since long acicular crystals have previously been shown to be highly toxic (7).

It is also of interest that tests conducted on fibreboard may far underestimate the true potency of deposits on bark and results in practice may be expected to be much better.

Toxicity by Sex

When the pooled mortality data from these field tests with D. brevicomis were analyzed by sex, the males were shown to be consistently more susceptible than the females (table 18). This is in agreement with tests by topical application (6).

Table 18.--Male and female mortality of D. brevicomis adults emerging from ponderosa pine bolts sprayed with DDT-xylene solutions

Dose (mg. DDT/ft.^{2})	No. insects	No. dead (72 hr.)	Mortality (percent)	No. insects	No. dead (72 hr.)	Mortality (percent)
	Males			Females		
0	331	5	1	407	4	1
320	288	165	57	389	167	43
640	301	224	74	333	226	68
1,280	232	179	77	253	160	63

Discussion

The most promising aspect of the preceding study was the relatively high mortalities resulting from DDT-xylene applications to bark for the control of emerging adults. Previous laboratory studies of the potency of DDT compared to lindane (7) and studies reported herein on the potency of endrin and dieldrin have shown that DDT is not nearly as potent as some of these other chlorinated insecticides. It is foreseeable, therefore, that the control of emerging bark beetles can be made effective with the right insecticide in the right formulation.

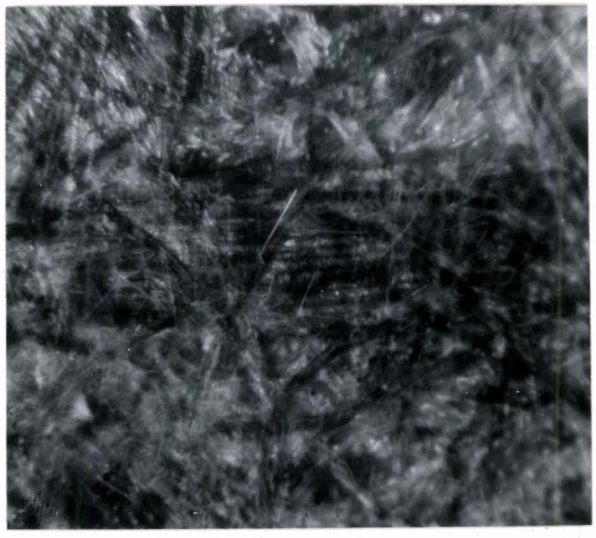

Figure 24.--Crystal structure of DDT-xylene solutions applied to fibreboard to parallel the tests on ponderosa pine bolts. The crystals were so fine that most were ill-defined and their combined effect was to produce a fuzzy appearance (54X).

The interpretation of the effect of dose is made difficult by the lack of control inherent in the nature of the tests. However, certain facts about relative potency can be mentioned and some correlations between potency and states of deposits can be pointed out. First of all, there was a decided improvement in toxicity when the dose was raised from 320 to 640 mg./ft.^{2} A second doubling of dose from 640 to 1,280 mg., on the basis of total mortality, was completely ineffective in improving toxicity. On the basis of day-to-day mortality data, the 640 mg. dose did prove to be slightly better as witnessed by higher kills from the ninth day on.

To explain these results on the basis of crystal growth requires solid quantitative data not only on crystal measurements and measurements of density and coverage but also measurements of the insecticide actually picked up on the body and appendages of the emerging insects. Such measurements were not made except on crystal dimensions.

The better showing by the two higher doses may well be due mainly to better coverage and higher crystal density made possible simply by a heavier initial deposit of insecticide. Also correlated with the 640 mg. dose were unique, broad, needle-like crystals that could conceivably be more effective than finer needles solely because of their greater mass; perhaps the insect picked up larger quantities of insecticide during a given exposure period on the 640 mg. deposit by way of the greater mass of insecticide adhering in the form of the broad, needle-like crystals. However, it was also noted that whenever the needle crystals were broad, they were usually less dense than the fine needles.

The inability to improve total mortality by doubling the dose from 640 to 1,280 mg. was very likely due, at least in part, to extensive crystallization by the 1,280 mg. dose in the form of tightly packed aggregates of needle-like crystals (figure 22B) mainly on the distal edges of bark scales projecting out from the general bark surface. A large part of the insecticide laid down was then made unavailable to the insect simply by being clumped in loci scattered over the bark surface. If these crystals had been evenly distributed, they would have been more accessible to the insect.

When the effect of size on mortality is removed by adjusting kills to the common denominator of average size, the day-to-day mortality curves become almost flat except for an initial steep ascent during the first 3 to 5 days following treatment. This suggests that the DDT-xylene deposits in these tests acquired maximum or nearly maximum toxicity shortly after they were created. The practical application of this is that control in the field would be made more efficient if the insecticide were applied a week or somewhat less before the insects began emerging.

It is not known why the smaller insects were killed easier. Possibly, the smaller insects pick up more insecticide per unit body

Figure 24.--Crystal structure of DDT-xylene solutions applied to fibreboard to parallel the tests on ponderosa pine bolts. The crystals were so fine that most were ill-defined and their combined effect was to produce a fuzzy appearance (54X).

The interpretation of the effect of dose is made difficult by the lack of control inherent in the nature of the tests. However, certain facts about relative potency can be mentioned and some correlations between potency and states of deposits can be pointed out. First of all, there was a decided improvement in toxicity when the dose was raised from 320 to 640 mg./ft.^{2} A second doubling of dose from 640 to 1,280 mg., on the basis of total mortality, was completely ineffective in improving toxicity. On the basis of day-to-day mortality data, the 640 mg. dose did prove to be slightly better as witnessed by higher kills from the ninth day on.

To explain these results on the basis of crystal growth requires solid quantitative data not only on crystal measurements and measurements of density and coverage but also measurements of the insecticide actually picked up on the body and appendages of the emerging insects. Such measurements were not made except on crystal dimensions.

The better showing by the two higher doses may well be due mainly to better coverage and higher crystal density made possible simply by a heavier initial deposit of insecticide. Also correlated with the 640 mg. dose were unique, broad, needle-like crystals that could conceivably be more effective than finer needles solely because of their greater mass; perhaps the insect picked up larger quantities of insecticide during a given exposure period on the 640 mg. deposit by way of the greater mass of insecticide adhering in the form of the broad, needle-like crystals. However, it was also noted that whenever the needle crystals were broad, they were usually less dense than the fine needles.

The inability to improve total mortality by doubling the dose from 640 to 1,280 mg. was very likely due, at least in part, to extensive crystallization by the 1,280 mg. dose in the form of tightly packed aggregates of needle-like crystals (figure 22B) mainly on the distal edges of bark scales projecting out from the general bark surface. A large part of the insecticide laid down was then made unavailable to the insect simply by being clumped in loci scattered over the bark surface. If these crystals had been evenly distributed, they would have been more accessible to the insect.

When the effect of size on mortality is removed by adjusting kills to the common denominator of average size, the day-to-day mortality curves become almost flat except for an initial steep ascent during the first 3 to 5 days following treatment. This suggests that the DDT-xylene deposits in these tests acquired maximum or nearly maximum toxicity shortly after they were created. The practical application of this is that control in the field would be made more efficient if the insecticide were applied a week or somewhat less before the insects began emerging.

It is not known why the smaller insects were killed easier. Possibly, the smaller insects pick up more insecticide per unit body

weight, for recent studies (5) on the pickup of lipophilic dyestuffs by insects of various sizes and tarsal development have shown that although larger insects pick up a larger total amount of material, the smaller insects pick up more material per unit body weight.

It is not surprising that states of deposits differed between the fibreboard blocks and the bark-covered bolts. The crystals produced on fibreboard were also represented on bark although bark deposits had a much wider range of different crystal sizes and shapes. The substrate on which insecticides are applied has a profound influence on the resulting states of deposits (1). It must also follow that the more heterogeneous the substrate, the more variable the states of deposits on it. Fibreboard is relatively uniform physically and the deposit on it varied only within a small range of size whereas the highly variable bark produced a much wider range in crystal structure.

RESULTS WITH I. CONFUSUS

Figure 25 (table 19, appended) shows day-to-day mortality beginning with the first day following treatment with the insecticide. The horizontal scale shows emergence up to 20 days when the test was stopped for lack of time. Emergence was still proceeding at its maximum rate and according to the number of beetles still remaining under the bark, emergence could have continued at its maximum for another week or 10 days.

Figure 25 shows that mortality at all three dose levels rose consistently for about a week and then fluctuated at a high level thereafter. And during this initial ascent, mortality varied directly with dose, starting at 57 percent for 320 mg., 67 percent for 640 mg. and 87 percent for 1,280 mg.

Throughout the full range of emergence, mortality tended to be better as dose was increased and this relationship held when the pooled mortality from total emergence was calculated (table 20).

Table 20.--Pooled mortality of Ips confusus adults

Dose (mg. DDT/ft.^{2})	No. of insects	No. dead (72 hr.)	Mortality (percent)
0	533	66	12
320	732	601	82
640	568	500	88
1,280	597	565	95

There was very little variation in the size of I. confusus adults in contrast to D. brevicomis and there was no tendency for the average size of the beetles to decrease or increase from day to day. Consequently, size was not a factor in the mortality observed.

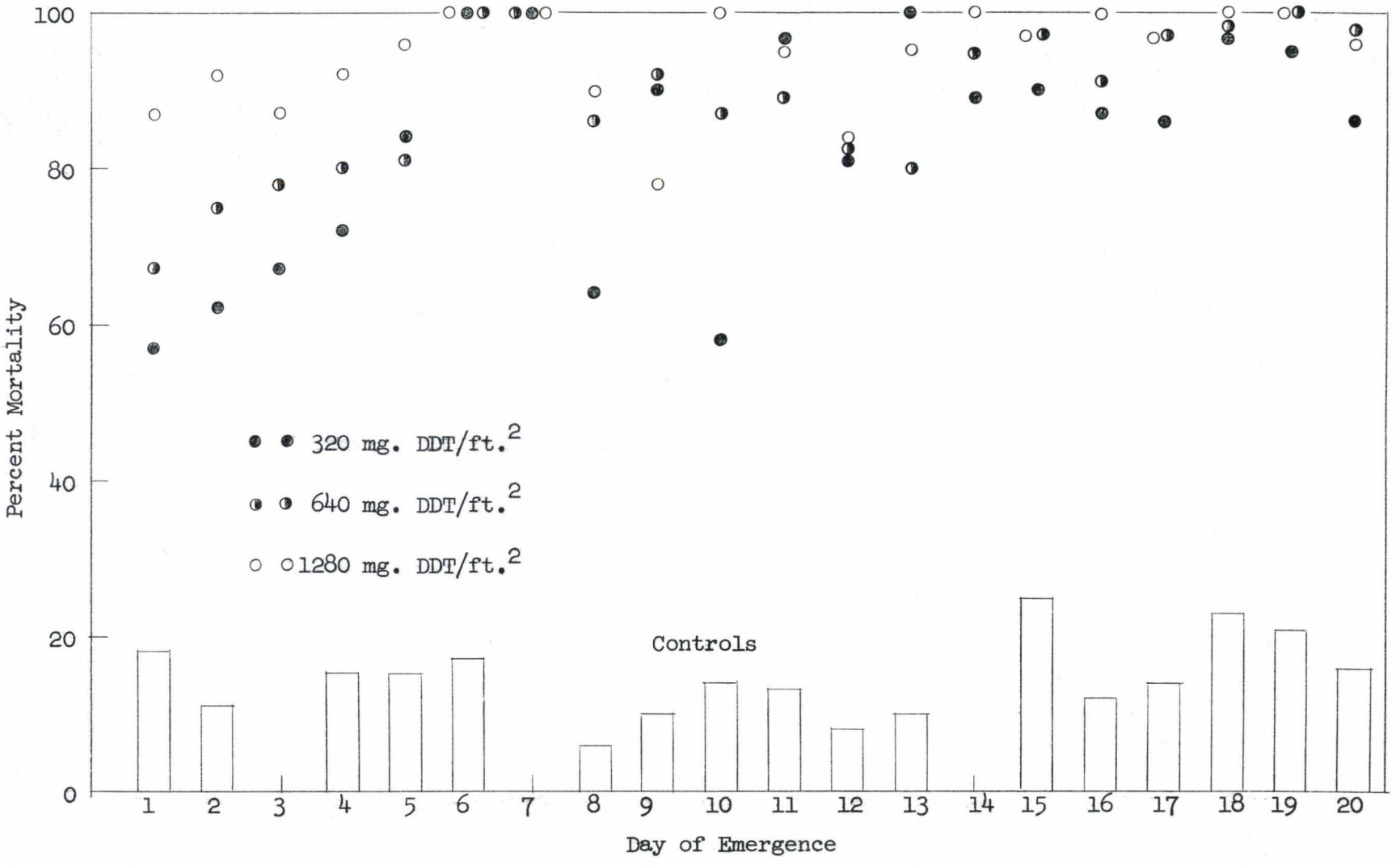

Figure 25.--Mortality of Ips confusus adults emerging from ponderosa pine bolts treated with DDT-xylene solutions.

States of Deposits

The states of deposit in these tests were very similar to those in the tests with D. brevicomis (figures 22 and 23) except that the 1,280 mg. dose did not contain the localized needle aggregates pictured in figure 22B. Why these crystal aggregates did not appear in these tests of 1,280 mg. DDT is not known. All experimental conditions were the same as in the tests with D. brevicomis except that different host trees were used and the tests were begun after the D. brevicomis tests were concluded so environmental conditions may have differed.

The most conspicuous difference in the deposits of the three dose levels was the almost complete absence of needle crystals of more than 50μ in length at the 320 mg. dose. The 640 and 1,280 mg. doses produced many crystals reaching 100μ with the 1,280 mg. dose having more of these long crystals than the two lower doses. So, as dose was increased, the abundance of long needle crystals increased. The great majority of remaining crystals were 20 to 50μ long. Coverage also appeared to increase as dose was increased, so this plus the increasing proportion of long needle crystals were the only characteristics that could be correlated with increasing dose and toxicity. There was a scattering of broad needle crystals reaching 20μ in width more or less equally represented in the deposits of all three dose levels.

Parallel Test on Fibreboard

Parallel tests were again carried out on fibreboard by exposing I. confusus adults for one minute to fibreboard blocks treated at the same dose levels and at the same time as tests were begun on the experimental bolts. Exposures were made on the 3rd and 9th day after the fibreboard blocks were treated and the results were averaged (table 21).

Table 21.-- Mortality of Ips confusus adults exposed for one minute to DDT-xylene solutions on fibreboard

Dose (mg. DDT/ft.^{2})	No. insects	No. dead (72 hr.)	Mortality (percent)
0	50	1	2
320	100	8	8
640	100	20	20
1,280	100	49	49

In these tests, mortality increased directly with dose, from 8 percent at 320 mg. to 49 percent at 1,280 mg. Significantly, this same relationship was seen in the tests with treated bolts. The increasing mortality with increasing dose shown in table 21 was correlated with crystal growth; coverage increased slightly with each increment of dose.

The deposits on these fibreboard blocks were identical with those obtained on the fibreboard blocks used to parallel the field tests with D. brevicomis. Yet there was far less mortality among the D. brevicomis adults, suggesting that the DDT deposits studied are more toxic to I. confusus. This seems to be borne out by additional bioassay tests of DDT-acetone deposits on fibreboard shown in table 22. The deposits were produced and bioassayed at the same time with D. brevicomis and I. confusus adults emerging from the same infested log. D. brevicomis averaged 20 percent mortality and I. confusus averaged 75 percent mortality. Relative toxicity of DDT to D. brevicomis and I. confusus by topical application of acetone solutions also shows I. confusus to be the more susceptible (10).

Table 22.--Comparative mortalities of Dendroctonus brevicomis and Ips confusus adults exposed for one minute to DDT-acetone deposits on fibreboard

No. insects	No. dead (72 hr.)	Mortality (percent)	No. dead (72 hr.)	Mortality (percent)
	D. brevicomis		I. confusus	
10	2	20	10	100
10	1	10	6	60
10	3	30	5	50
10	1	10	9	90
10	3	30	9	90
10	1	10	5	50
10	1	10	8	80
10	3	30	7	70
10	2	20	8	80
10	3	30	8	80
100	20	20	75	75
Controls:				
20	1	5	2	10

Toxicity by Sex

When the pooled mortality data are analyzed by sex, the females show a consistently, though slightly, greater mortality (table 23). Greater toxicity to the female sex was also shown in studies of DDT-acetone solutions by topical application (9). The data in table 23 show an unbalanced sex ratio. Males accounted for only 35 percent of the total.

Table 23.--Male and female mortality of Ips confusus adults emerging from ponderosa pine bolts sprayed with DDT-xylene solutions

Dose (mg. DDT/ft.^{2})	No. insects	No. dead (72 hr.)	Mortality (percent)	No. insects	No. dead (72 hr.)	Mortality (percent)
	Males			Females		
0	159	14	9	374	52	14
320	265	205	77	467	396	85
640	223	185	83	345	315	91
1,280	211	195	92	386	370	96

Mortality of Predators

All clerid and ostomid adults were collected as they emerged to determine the possible effects of the insecticide treatments on these predators. They received the same post-emergence care given the bark beetles. Since only a small number of predators emerged, the data from tests with D. brevicomis infested bolts and I. confusus infested bolts were combined. The data from each dose were also combined and the results, given in table 24, show no mortality whatever. There was one ostomid species, Temnochila virescens (Fab.), and two clerid species, Thanasimus lecontei Wolc. and Enoclerus sphegeus Fab.3/ Only a few of the clerids were the latter species.

Table 24.--Mortality of clerid and ostomid predators emerging from ponderosa pine bolts treated with DDT-xylene solutions

Conditions of bolts	No. insects	No. dead (72 hr.)	Mortality (percent)
	Clerids		
Treated	15	0	0
Control	5	0	0
	Ostomids		
Treated	3	0	0
Control	1	0	0

3/ These are tentative identifications. Specimens have been sent to the U.S. National Museum, Washington, D.C.

Discussion

The relatively high mortalities produced by the DDT deposits suggest that the residual-type insecticides may provide effective control, particularly when it is remembered that DDT was one of the least potent residuals tested by topical application (6).

Toxicity continued to improve with each doubling of dose. This differed from the results with D. brevicomis, and the only obvious explanation that can be given is that the 1,280 mg. dose in tests with I. confusus did not crystallize in the form of tightly packed needle aggregates, which in effect reduce the total crystal mass that is readily available to the insect.

Parallel tests on fibreboard were in agreement with tests on the pine bolts, i.e., mortality improved with each doubling of dose in both tests. Ordinarily, tests of DDT solutions applied to fibreboard showed optimum toxicity at some dose between 160 and 1,280 mg. DDT/ft.^{2} (7). However, this occurred when treated fibreboard blocks were held indoors and thus were not exposed to the environment. Other tests, discussed in this report, showed that the environment may have strong effects on the development of deposits and an optimum dose cannot be predicted on deposits outdoors from information gained through tests of deposits held indoors.

In order to assure more uniform application of insecticides to experimental pine bolts in future field studies of residual-type insecticides, a turntable was designed on which test bolts can be rotated at a constant 22 R.P.M. (figure 26). With a constant rotational speed, a uniform initial pressure in the sprayer, and equal volumes of insecticide in the sprayer, some of the variability in results may be eliminated. Allowance has been made to permit the attachment of different-sized pulleys for increasing or decreasing rotational speed if this should prove necessary.

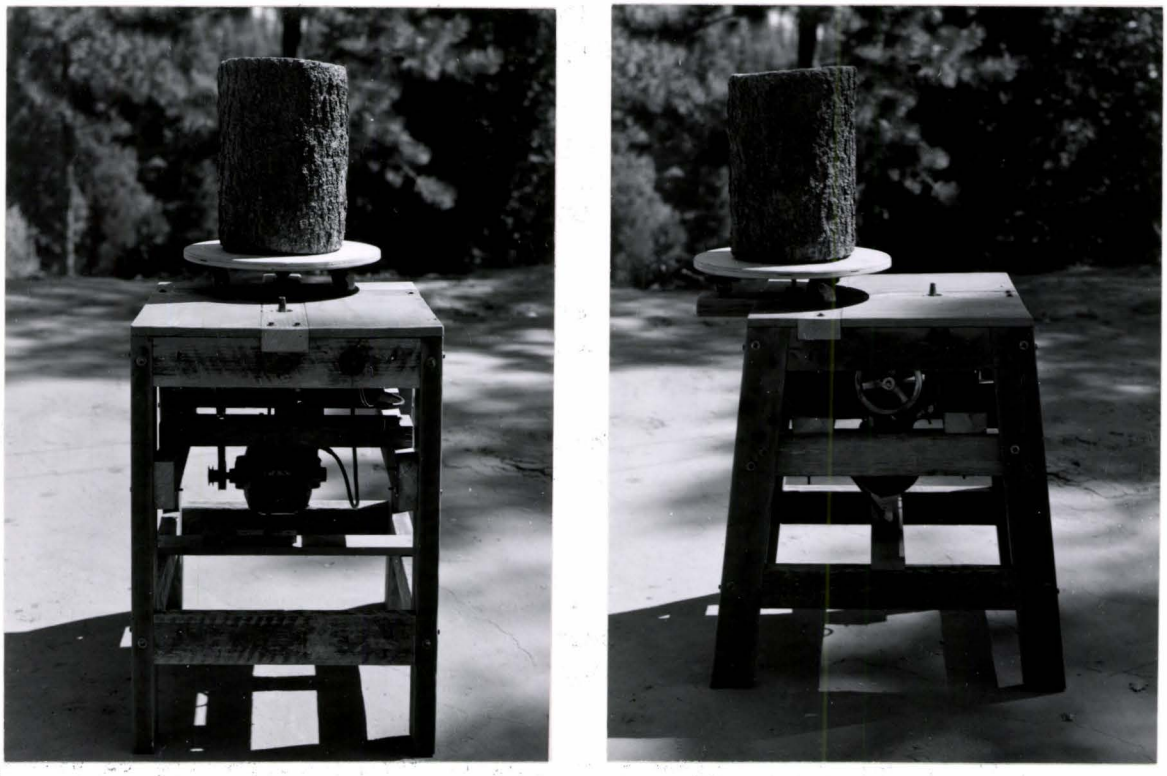

Figure 26.--Front and side views of turntable to be used in field tests of residual-type insecticides. The turntable proper is mounted on three ball-bearing castors and is powered by a one-quarter horsepower motor.

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APPENDIX

Table 1.--The effect of dose on mortality of Ips confusus adults exposed to DDT-acetone deposits for one minute

Dose (mg.DDT/ft.^{2})	No. males	No. dead (72.hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
0	26	0	0	94	15	16	120	15	12
320	16	1	6	34	25	73	50	26	52
480	17	6	35	33	19	58	50	25	50
640	17	4	23	33	22	67	50	26	52
800	23	0	0	27	18	67	50	18	36
960	23	1	4	27	18	67	50	19	38
1,120	15	3	20	35	21	60	50	24	48
1,280	19	2	10	31	17	55	50	19	38
1,440	9	0	0	41	16	39	50	16	32
1,600	19	2	10	31	12	39	50	14	28
1,760	15	2	13	35	24	69	50	26	52
1,920	11	1	9	39	24	61	50	25	50
2,080	9	0	0	41	26	63	50	26	52
2,240	12	1	8	38	25	66	50	26	52
2,400	15	2	13	35	20	57	50	22	44
2,560	11	2	18	39	18	46	50	20	40

Table 2.--The effect of dose on mortality of Ips confusus adults exposed to endrin - acetone deposits for one minute

Dose (mg.endrin/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
0	34	0	0	76	8	10	110	8	7
320	19	12	63	31	30	97	50	42	84
480	19	18	95	31	28	90	50	46	92
640	15	14	93	35	34	97	50	48	96
800	17	15	88	33	33	100	50	48	96
960	24	24	100	26	26	100	50	50	100
1,120	11	11	100	39	39	100	50	50	100
1,280	16	14	87	34	33	97	50	47	94
1,440	14	12	86	36	36	100	50	48	96
1,600	22	19	86	28	28	100	50	47	94
1,760	21	21	100	29	29	100	50	50	100
1,920	16	16	100	34	34	100	50	50	100
2,080	20	20	100	30	30	100	50	50	100
2,240	25	25	100	25	25	100	50	50	100
2,400	22	21	95	28	28	100	50	49	98
2,560	12	12	100	38	38	100	50	50	100

Table 3.--The effect of dose on mortality of Ips confusus adults exposed to dieldrin - acetone deposits for one minute

Dose (mg. dieldrin/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
0	20	0	0	70	7	10	90	7	8
80	27	19	70	23	22	96	50	41	82
120	29	23	79	21	21	100	50	44	88
160	19	12	63	31	30	97	50	42	84
200	17	6	35	33	32	97	50	38	76
240	16	10	62	34	32	94	50	42	84
280	18	11	61	32	31	97	50	42	84
320	17	11	65	33	33	100	50	44	88
360	23	11	48	27	23	85	50	34	68
400	7	4	57	43	39	91	50	43	86
440	12	2	17	38	29	76	50	31	62
480	12	7	58	38	32	84	50	39	78
520	16	10	62	34	29	85	50	39	78
560	16	9	56	34	32	94	50	41	82
600	11	4	36	39	30	77	50	34	68
640	7	2	35	43	40	93	50	42	84

Table 4.--The influence of concentration on mortality of Ips confusus adults exposed to DDT-acetone deposits for one minute

Dose (mg. DDT/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality &standard error
				Concentration increasing					
0	11	0	0	79	4	5	90	4	4
160	35	9	26	65	43	66	100	52	52 ± 5
320	30	17	57	70	62	89	100	79	79 ± 2
640	39	17	41	61	46	75	100	62	62 ± 4
1,280	22	8	36	77	58	75	99	66	67 ± 5
Total	137			352			489		
				Concentration constant					
0	11	0	0	79	4	5	90	4	4
160	10	4	40	90	55	61	100	59	59 ± 3
320	42	26	62	58	49	84	100	75	75 ± 3
640	46	11	24	54	33	61	100	44	44 ± 5
1,280	42	13	31	58	52	90	100	65	65 ± 6
Total	151			339			490		

Table 5.--The influence of concentration on mortality of Ips confusus adults exposed to dieldrin-acetone deposits for one minute

Dose (mg. dieldrin/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				Concentration increasing					
0	28	0	0	109	9	8	137	9	7
80	16	0	0	34	14	41	50	14	28 ± 5
160	16	15	94	34	34	100	50	49	98 ± 2
320	7	5	71	43	31	72	50	36	72 ± 10
640	14	7	50	36	18	50	50	25	50 ± 5
Total	81			256			337		
				Concentration constant					
0	28	0	0	109	9	8	137	9	7
80	27	19	70	23	22	96	50	41	82 ± 8
160	19	12	63	31	30	97	50	42	84 ± 4
320	17	11	65	33	33	100	50	44	88 ± 5
640	7	2	35	43	40	93	50	42	84 ± 4
Total	98			239			337		

Table 7.--Mortality of Ips confusus adults exposed for one minute to DDT-acetone deposits aged for one month under various degrees of exposure

Dose (mg. DDT/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality and standard error
0	104	1	1	121	4	3	225	5	2
				No exposure					
320	53	22	41	47	32	68	100	54	54 ± 5
640	38	4	10	62	29	47	100	33	33 ± 3
1,280	57	7	12	43	21	49	100	28	28 ± 4
				Vertical facing east					
320	54	36	67	46	43	93	100	79	79 ± 4
640	48	33	69	52	49	94	100	82	82 ± 4
1,280	63	25	40	37	25	68	100	50	50 ± 6
				Vertical facing south					
320	40	28	70	60	54	90	100	82	82 ± 5
640	52	28	54	48	38	79	100	66	66 ± 6
1,280	54	26	48	46	33	72	100	59	59 ± 4
				Horizontal					
320	59	5	8	41	20	49	100	25	25 ± 6
640	43	14	32	57	41	72	100	55	55 ± 6
1,280	46	29	63	54	45	83	100	74	74 ± 4

Table 8.--Mortality of Ips confusus adults exposed for one minute to DDT-acetone deposits aged for two and one-half months under various degrees of exposure

Dose (mg. DDT/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality and standard error
0	2	0	0	18	0	0	20	0	0
No exposure									
320	14	8	57	36	34	94	50	42	84 ± 5
640	13	1	8	37	23	62	50	24	48 ± 5
1,280	20	6	30	30	22	73	50	28	56 ± 10
Vertical facing east									
320	15	11	73	35	34	97	50	45	90 ± 3
640	7	6	86	43	42	98	50	48	96 ± 2
1,280	16	14	87	34	33	97	50	47	94 ± 4
Vertical facing south									
320	16	14	87	34	34	100	50	48	96 ± 3
640	17	16	94	33	32	97	50	48	96 ± 4
1,280	15	8	53	35	29	83	50	37	74 ± 6
Horizontal									
320	23	3	13	27	19	70	50	22	44 ± 7
640	18	2	11	32	25	78	50	27	54 ± 9
1,280	20	13	65	30	27	90	50	40	80 ± 5

Table 10.--The mortality of Ips confusus adults exposed for one minute to DDT-acetone and DDT-xylene deposits at three dose levels on moist and dry fibreboard substrates

Dose (mg. DDT/ft.^{2})	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality and standard error
				DDT-acetone; dry substrate					
0	4	0	0	36	0	0	40	0	0
320	19	8	42	31	28	90	50	36	72 ± 7
640	15	5	33	35	26	74	50	31	62 ± 4
1,280	22	0	0	28	17	61	50	17	34 ± 4
				DDT-acetone; moist substrate					
320	18	13	72	32	28	87	50	41	82 ± 6
640	17	5	29	33	17	51	50	22	44 ± 11
1,280	18	1	5	32	13	41	50	14	28 ± 5
				DDT-xylene; dry substrate					
320	16	6	37	34	31	91	50	37	74 ± 5
640	10	10	100	40	38	95	50	48	96 ± 2
1,280	17	14	82	33	29	88	50	43	86 ± 5
				DDT-xylene; moist substrate					
320	15	7	47	35	26	74	50	33	66 ± 10
640	15	14	93	35	35	100	50	49	98 ± 2
1,280	7	5	71	43	35	81	50	40	80 ± 13

Table 11.--Mortality of Ips confusus adults exposed to DDT-acetone deposits under an intact watch glass and one with its center cut out to test the fumigating action of DDT deposits

Exposure time (minutes)	Watch glass intact			Watch glass with center removed		
	No. insects	No. dead (72 hr.)	Mortality (percent)	No. insects	No. dead (72 hr.)	Mortality (percent)
0	100	3	3	100	3	3
0.25	20	8	40	--	-	-
0.5	40	28	70	40	28	70
1.0	40	25	62	40	27	67
1.5	30	21	70	30	23	77
2	40	30	75	40	30	75
3	20	13	65	20	16	80
4	30	27	90	30	28	93
5	20	19	95	20	17	85
6	20	20	100	20	20	100
7	20	18	90	20	17	85
10	20	20	100	20	17	85
15	20	19	95	20	15	75
20	20	18	90	20	19	95

Table 12.--Mortality of D. brevicomis adults emerging from ponderosa pine bolts treated with DDT-xylene solutions

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				320 mg. DDT/ft.^{2}					
1	21	3	14	22	2	9	43	5	12
2	33	13	39	51	13	25	84	26	31
3	26	12	46	34	12	35	60	24	40
4	22	11	50	25	10	40	47	21	45
5	23	13	56	33	17	51	56	30	54
6	25	15	60	33	17	51	58	32	55
7	26	14	54	32	17	53	58	31	53
8	22	16	73	41	13	32	63	29	46
9	16	9	56	37	21	57	53	30	57
10	16	11	69	12	5	42	28	16	57
11	13	11	85	19	6	32	32	17	53
12	16	9	56	19	14	74	35	23	66
13	18	17	94	15	9	60	33	26	79
14	10	10	100	13	9	69	23	19	83
15	1	1	100	3	2	67	4	3	75
Total	288	165		389	167		677	332	
Average			57%			43%			49%

Table 12.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				640 mg. DDT/ft.^{2}					
1	14	4	29	20	5	25	34	9	26
2	29	19	65	38	24	63	67	43	64
3	18	16	89	30	15	50	48	31	65
4	11	8	73	16	14	87	27	22	81
5	27	18	67	20	13	65	47	31	66
6	37	25	68	38	20	53	75	45	60
7	35	25	71	31	22	71	66	47	71
8	33	22	67	36	22	61	69	44	64
9	34	28	82	35	30	86	69	58	84
10	19	19	100	20	16	80	39	35	90
11	15	11	73	14	12	86	29	23	79
12	13	13	100	10	9	90	23	22	96
13	6	6	100	9	9	100	15	15	100
14	5	5	100	9	8	89	14	13	93
15	5	5	100	7	7	100	12	12	100
Total	301	224		333	226		634	450	
Average			74%			68%			71%

Table 12.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				1,280 mg. DDT/ft.^{2}					
1	5	2	40	9	5	55	14	7	50
2	11	9	82	23	12	52	34	21	62
3	19	14	74	23	13	56	42	27	64
4	12	10	83	19	11	58	31	21	68
5	16	14	87	19	15	79	35	29	83
6	22	15	68	22	13	59	44	28	64
7	28	24	86	30	16	53	58	40	69
8	22	15	68	23	15	65	45	30	67
9	24	19	79	26	17	65	50	36	72
10	23	17	74	12	5	42	35	22	63
11	15	12	80	6	5	83	21	17	81
12	18	14	78	16	13	81	34	27	79
13	6	6	100	12	8	67	18	14	78
14	10	7	70	2	2	100	12	9	75
15	1	1	100	11	10	91	12	11	92
Total	232	179		253	160		485	339	
Average			77%			63%			70%

Table 12.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				Controls					
1	39	0	0	40	0	0	79	0	0
2	42	1	2	48	0	0	90	1	1
3	27	2	7	40	0	0	67	2	3
4	21	0	0	30	1	3	51	1	2
5	23	0	0	29	0	0	52	0	0
6	27	0	0	32	0	0	59	0	0
7	35	0	0	36	0	0	71	0	0
8	33	1	3	28	0	0	61	1	2
9	28	0	0	35	1	3	63	1	2
10	17	0	0	25	0	0	42	0	0
11	20	0	0	17	0	0	37	0	0
12	8	0	0	23	2	9	31	2	6
13	8	1	12	15	0	0	23	1	4
14	3	0	0	6	0	0	9	0	0
15	0	0	-	3	0	0	3	0	0
Total	331	5		407	4		738	9	
Average			1%			1%			1%

Table 14.--Average size of Dendroctonus brevicomis adults from each day's emergence from ponderosa pine bolts sprayed with DDT-xylene solutions

Day of emergence	Average length of elytra (mm.)			
	320 mg./ft.^{2} DDT	640 mg./ft.^{2} DDT	1,280 mg./ft.^{2} DDT	Control
1	2.53	2.54	2.60	2.53
2	2.58	2.52	2.52	2.49
3	2.51	2.58	2.42	2.38
4	2.38	2.33	2.47	2.36
5	2.45	2.38	2.41	2.43
6	2.44	2.41	2.42	2.40
7	2.44	2.41	2.57	2.44
8	2.41	2.31	2.41	2.43
9	2.35	2.26	2.41	2.49
10	2.39	2.21	2.43	2.35
11	2.36	2.27	2.29	2.45
12	2.22	2.16	2.35	2.33
13	2.32	2.07	2.30	2.44
14	2.15	2.12	2.37	2.34
15	2.02	1.97	2.20	2.27

Table 15.--The influence of body size on the mortality response of Dendroctonus brevicomis adults emerging from ponderosa pine bolts sprayed with DDT-xylene solutions

Length elytron (mm.)	320 mg. DDT/ft.^{2}			640 mg. DDT/ft.^{2}			1,280 mg. DDT/ft.^{2}		
	No. insects	No. dead	Percent mortality	No. insects	No. dead	Percent mortality	No. insects	No. dead	Percent mortality
1.5	2	2	100	4	4	100	1	1	100
1.6	4	4	100	8	8	100	6	6	100
1.7	13	12	92	7	7	100	8	7	87
1.8	10	9	90	23	22	96	16	13	81
1.9	12	12	100	22	20	91	17	14	82
2.0	29	23	79	31	23	74	22	11	50
2.1	44	32	73	62	53	85	36	24	67
2.2	53	33	62	66	63	95	37	26	70
2.3	100	56	56	68	46	68	47	37	79
2.4	89	48	54	93	63	68	47	34	72
2.5	94	43	46	86	61	71	57	40	70
2.6	78	28	36	58	34	59	50	39	78
2.7	53	14	26	37	18	49	44	28	64
2.8	46	8	17	31	14	45	47	29	62
2.9	32	7	22	21	11	50	23	14	61
3.0	15	1	7	12	2	17	19	12	63
3.1	3	0	0	2	1	50	8	4	50
3.2	0	-	-	3	0	0	0	-	--

Table 16.--Adjusted mortality of Dendroctonus brevicomis adults according to size

Day of emergence	Average size (mm.) S	Actual mortality (percent) M	Deviation from mean size (mm.) (S-2.42) D	Mortality adjustment (±percent) d x 0.7 x 100 P	Adjusted mortality (percent) M + P
1	2.53	12	+ 0.11	+ 8	20
2	2.58	31	+ 0.16	+ 11	42
3	2.51	40	+ 0.09	+ 6	46
4	2.38	45	- 0.04	- 3	42
5	2.45	54	± 0.03	+ 2	56
6	2.44	55	+ 0.02	+ 1	56
7	2.44	53	+ 0.02	+ 1	54
8	2.41	46	- 0.01	- 1	45
9	2.35	57	- 0.07	- 5	52
10	2.39	57	- 0.03	- 2	55
11	2.36	53	- 0.06	- 4	49
12	2.22	66	- 0.20	- 14	52
13	2.32	79	- 0.10	- 7	72
14	2.15	83	- 0.27	- 19	64
15	2.02	75	- 0.40	- 28	47

Table 19.--Mortality of Ips confusus adults emerging from ponderosa pine bolts treated with DDT-xylene solutions

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				320 mg. DDT/ft.^{2}					
1	2	2	100	26	14	54	28	16	57
2	24	11	46	45	32	71	69	43	62
3	11	5	45	31	23	74	42	28	67
4	11	5	45	32	26	81	43	31	72
5	9	5	55	23	22	96	32	27	84
6	3	3	100	8	8	100	11	11	100
7	3	3	100	4	4	100	7	7	100
8	2	1	50	9	6	67	11	7	64
9	4	3	75	16	15	94	20	18	90
10	24	11	46	12	10	83	36	21	58
11	8	8	100	21	20	95	29	28	97
12	11	8	73	20	17	85	31	25	81
13	15	15	100	9	9	100	24	24	100
14	14	11	79	14	14	100	28	25	89
15	10	9	90	30	27	90	40	36	90
16	24	21	87	37	32	86	61	53	87
17	18	15	83	39	34	87	57	49	86
18	30	28	93	32	32	100	62	60	97
19	24	24	100	34	31	91	58	55	95
20	18	17	94	25	20	80	43	37	86
Total	265	205		467	396		732	601	
Average			77%			85%			82%

Table 19.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				640 mg. DDT/ft.^{2}					
1	3	2	67	18	12	67	21	14	67
2	22	11	50	38	34	89	60	45	75
3	14	9	64	31	26	84	45	35	78
4	15	9	60	20	19	95	35	28	80
5	7	5	71	24	20	83	31	25	81
6	2	2	100	4	4	100	6	6	100
7	1	1	100	5	5	100	6	6	100
8	5	4	80	9	8	89	14	12	86
9	5	5	100	7	6	86	12	11	92
10	11	11	100	13	10	77	24	21	87
11	8	6	75	10	10	100	18	16	89
12	3	2	67	8	7	87	11	9	82
13	7	4	57	13	12	92	20	16	80
14	9	8	89	12	12	100	21	20	95
15	15	15	100	18	17	94	33	32	97
16	23	20	87	20	19	95	43	39	91
17	12	12	100	26	25	96	38	37	97
18	16	15	94	26	26	100	42	41	98
19	26	26	100	15	15	100	41	41	100
20	19	18	95	28	28	100	47	46	98
Total	223	185		345	315		568	500	
Average			83%			91%			88%

Table 19.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				1,280 mg. DDT/ft.^{2}					
1	4	3	75	19	17	89	23	20	87
2	18	16	89	44	41	93	62	57	92
3	13	10	77	34	31	91	47	41	87
4	12	10	83	26	25	96	38	35	92
5	3	3	100	23	22	96	26	25	96
6	3	3	100	5	5	100	8	8	100
7	0	-	-	7	7	100	7	7	100
8	4	3	75	6	6	100	10	9	90
9	9	5	55	9	9	100	18	14	78
10	4	4	100	10	10	100	14	14	100
11	7	6	86	15	15	100	22	21	95
12	4	3	75	14	12	86	18	15	83
13	5	5	100	15	14	93	20	19	95
14	9	9	100	11	11	100	20	20	100
15	11	11	100	23	22	96	34	33	97
16	22	22	100	18	18	100	40	40	100
17	8	8	100	21	20	95	29	28	97
18	23	23	100	34	34	100	57	57	100
19	29	29	100	21	21	100	50	50	100
20	23	22	96	31	30	97	54	52	96
Total	211	195		386	370		597	565	
Average			92%			96%			95%

Table 19.--Continued

Day of emergence	No. males	No. dead (72 hr.)	Percent mortality	No. females	No. dead (72 hr.)	Percent mortality	Total no. insects	No. dead (72 hr.)	Percent mortality
				Controls					
1	1	1	100	16	2	12	17	3	18
2	15	0	0	47	7	15	62	7	11
3	9	0	0	26	0	0	35	0	0
4	11	1	9	29	5	17	40	6	15
5	12	1	8	21	4	19	33	5	15
6	2	0	0	4	1	25	6	1	17
7	2	0	0	1	0	0	3	0	0
8	3	0	0	15	1	7	18	1	6
9	7	1	14	23	2	9	30	3	10
10	13	0	0	23	5	22	36	5	14
11	18	2	11	29	4	14	47	6	13
12	14	0	0	25	3	12	39	3	8
13	6	0	0	14	2	14	20	2	10
14	7	0	0	9	0	0	16	0	0
15	2	1	50	2	0	0	4	1	25
16	2	0	0	6	1	17	8	1	12
17	4	2	50	18	1	5	22	3	14
18	9	1	11	22	6	27	31	7	23
19	6	0	0	23	6	26	29	6	21
20	16	4	25	21	2	9	37	6	16
Total	159	14		374	52		533	66	
Average			9%			14%			12%

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